EVALUATION OF THE POTENTIAL
FOR
THE APPLICATION OF FLUE GAS CONDENSATION SYSTEMS TO INDUSTRIAL BOILERS

FINAL REPORT

BY

SNC INC.

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SUMMARY

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The potential of applying the flue gas condensing technology to large scale natural gas fired industrial boilers was evaluated in this work.

The heat loss due to combustion of hydrogen in natural gas in industrial boilers is as high as 10 to 15% of the fuel energy. The flue gases are vented at temperatures in excess of 150°C and carry recoverable energy in the form of sensible heat and the latent heat of water vapour produced by combustion of hydrogen in the fuel. The wasted energy may be reclaimed by using flue gas condensing heat recovery systems, constructed with corrosion resistant materials such as specialty steels and alloys, high temperature plastics, ceramics and high strength glass, etc.

The project involved a review of flue gas condensing technology, as well as evaluation, identification and application of commercial condensing heat recovery systems for large natural gas fired industrial boilers.

The 175,000 kilograms steam-per-hour main power boiler (#11) at Domtar Fine Papers Mill, Cornwall, Ontario was selected as a study case. The flue gases from the boiler were sampled and analysed. Operating data for the boiler were gathered from Domtar's records. Based on these data as well as flue gas analyses, design criteria were developed for a flue gas condensing system. These were revised during later stages of the study to include changes in the energy generation circuit at the plant.

The North American and European designers and/or vendors of flue gas condensing equipment were surveyed to identify commercial systems for large scale boilers. Request for design proposal/quotations were made to a number of them. Only three acceptable proposals were received:

1. TEFLON-coated copper tube flue gas condensor (the CHX System) by Condensing Heat Exchanger Corporation, U.S.A.

2. Borosilicate glass tube condensing heat exchanger by Flue Gas Resources, U.S.A.

3. Stainless steel (AISI 304) tube heat exchanger by Air Froehlich AG fuer Energierueckgewinnung of Switzerland.

The CHX system has been designed to recover the maximum amount of wasted energy. The efficiency of Boiler #11 would be increased by about 5.75 percent by reclaiming on an average 24 371 Mega-Joule-per-hour waste heat. The glass tube heat exchanger has been designed to recover an average 22 240 Mega-Joule-per-hour. The steel tube heat exchanger would recover about 15 138 Mega-Joule-per-hour.

The costs of the saved energy for the CHX system, the glass tube heat exchanger, and the stainless steel tube heat exchanger are $9.60/GJ, $8.53/GJ and $9.36/GJ, respectively.

An order of magnitude capital cost estimate was developed for retrofitting Boiler #11 with a flue gas condensing heat recovery system. The capital cost estimates for the CHX System, the glass tube heat exchanger, the Stainless Steel tube heat exchanger are $2,012,869, $1,632,096 and $1,218,956 respectively with an accuracy of ±30%.

SOMMAIRE

SOMMAIRE

Cette étude porte sur l'évaluation des technologies de récupération par condensation des fumées pour les chaudières à gaz naturel de capacité industrielle. La perte d'énergie des chaudières industrielles fonctionnant au gaz est de l'ordre de 10 à 15 pour cent. L'évacuation des fumées se fait à des températures dépassant 150° et elles contiennent de l'énergie récupérable sous forme de chaleur sensible et de chaleur latente produites lors de la combustion de l'hydrogène du carburant. La récupération d'énergie peut se faire en utilisant des systèmes de récupérateurs à condensation construits avec des matériaux résistant à la corrosion, tels que les aciers traités et les alliages, les plastiques résistant aux températures élevées, les céramiques, le verre à résistance élevée, etc.

Le projet comportait l'inventaire et l'étude des technologies de condensation des fumées afin d'identifier celles susceptibles d'améliorer le rendement des chaudières de capacité industrielle fonctionnant au gaz.

Le projet comprenait également l'évaluation de la chaudière principale (n° 11) d'une capacité de 175 000 kg/heure de vapeur de l'usine de Domtar à Cornwall. On a procédé à un prélèvement d'échantillons et à l'analyse des fumées de la chaudière. On a ensuite obtenu les données du fonctionnement de la chaudière à partir des dossiers de Domtar. Les critères de conception du système de condensation des fumées ont été établis d'après ces analyses et ces données. Les critères de conception ont été révisés au cours de l'étude afin de tenir compte des modifications apportées au circuit de production d'énergie.

Une recherche a été effectuée auprès des manufacturiers et des fournisseurs d'équipement de condensation des fumées sur le

marché nord-américain et européen, dans le but d'identifier les systèmes commerciaux qui se prêtent le mieux à être utilisés pour les chaudières de grande capacité. Suite à cet examen, nous avons demandé à plusieurs d'entre eux de nous fournir des soumissions. De toutes les soumissions reçues, seules trois ont retenu notre attention. Il s'agit notamment de:

1. récupérateur à condensation des gaz de carneau avec tubes en cuivre chemisés de teflon (système CHX), de la corporation Condensing Heat Exchanger, E.U.

2. échangeur de chaleur à condensation avec tubes en verre aux borosilicates, de la Flue Gas Resources, E.U.

3. échangeur de chaleur avec tubes en acier inoxydable (AISI 304) de la Air Froehlich AG fuer Energierueckgewinnung, Suisse

C'est le système CHX qui s'est avéré le plus efficace pour la récupération d'énergie. Son installation sur la chaudière no. 11 en améliorerait le rendement de 5.75 %, ce qui représente une moyenne de 24 371 megajoules/heure d'énergie perdue contre 22 240 mégajoules/heures pour l'échangeur de chaleur à condensation avec tubes en verre et 15 138 megajoules/heure pour l'échangeur de chaleur avec tubes en acier.

L'énergie ainsi récupérée représente une économie de 3.95$/GJ pour le système CHX, 2.54$/GJ pour l'échangeur de chaleur à tubes en verre, et 1.77$/GJ pour l'échangeur de chaleur à tubes en acier.

Une estimation des coûts pour l'installation d'un système de récupération d'énergie par condensation des fumées a été préparée pour la chaudière n° 11, avec une marge de précision de ±30 %. Ils sont de l'ordre de 1.3 à 2 millions $.

Notre étude démontre qu'une économie de 774 619 $ par an pourraît être réalisée en installant l'échangeur de chaleur à condensation à tubes en verre, en supposant que le coût du gaz naturel soit de 4.05 %/megajoule. Ce système s'avère le plus avantageux des trois considérés à cause de la période de remboursement, qui est la plus courte.

Il semble que l'installation de l'échangeur de chaleur à condensation avec tubes en verre de la compagnie Flue Gas Resources et l'installation d'une cheminée en fibre de verre soit la meilleure solution pour la chaudière nº 11 de l'usine de Domtar à Cornwall.

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1.0 INTRODUCTION

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Flue gases vented from industrial furnaces, boilers, incinerators and other combustion equipment represent potential sources of low temperature thermal energy. These gases carry large amount of recoverable energy in the form of low temperature sensible heat and latent heat of vaporization of water formed by combustion of fuel hydrogen. Typically, the combustion systems designed prior to 1980's recover less than 80% of the energy in natural gas. The remaining energy is discharged into the atmosphere. In particular, boilers fired with natural gas have substantially more latent heat of vaporization of water available in the flue gas because of the greater hydrogen content in the fuel. Heat losses due to formation of water vapour range from 8% to 12% when natural gas is used as boiler fuel. There are two main factors which have inhibited the recovery of energy lost in the flue gas:

1. The dearth of low cost materials of construction which can resist corrosion when flue gas is cooled to a temperature below the dew point of its acidic components, such as oxides of sulphur and nitrogen.

2. The limited utility of the low temperature energy recovered by cooling flue gases below 150°C.

Nevertheless, since the early 1970's, major consumers of industrial energy have become increasingly aware of the lost energy and the need to find suitable means of recovering it.

Research on materials of construction and their corrosion resistant properties has promoted development of several advanced materials which can withstand highly corrosive substances. Such materials include metals, plastics and composites.

The payback periods of heat recovery systems have been reduced due to the increase in energy costs and relatively stable equipment costs. This has raised the economic worth of recovering energy by cooling flue gases to temperatures as low as 40°C.

The present study, which was commissioned by the Energy Research Laboratories of the Canada Centre for Mineral and Energy Technology (CANMET), aimed at determining the viability of heat recovery by condensing the flue gas.

The main objective of this study was to evaluate the potential energy savings generated by the application of flue gas condensing systems to industrial boilers fired with natural gas. The pulp and paper industry, which consumes enormous amounts of energy in the pulping process and paper mills, was identified as one of the major industrial sectors which could benefit by application of flue gas condensation technology.

In order to ensure the applicability of study results to natural gas fired industrial boilers across Canada, it was necessary to identify and select a typical site. The Domtar Fine Papers Mill at Cornwall, Ontario, which has three large boilers, was selected based on a preliminary survey of natural gas fired boilers.

The study involved:

- Reviewing condensing heat recovery technology and identification of North American and European manufacturers of flue gas condensing systems;

- Conducting flue gas analysis and an energy audit of the main power boiler Domtar Fine Papers Mill in Cornwall in order to develop specifications for a suitable flue gas condensation system;

- Developing preliminary designs for a heat recovery system which can be retrofitted to the natural gas fired main power boiler at Domtar Fine Papers Mill;

2.0 REVIEW OF FLUE GAS CONDENSATION TECHNOLOGY

2.0 REVIEW OF FLUE GAS CONDENSATION TECHNOLOGY

The energy released by combustion of solid, liquid or gaseous fuels is carried by product gases in the form of sensible heat, and latent heat. The recovery of this energy by direct or indirect heat transfer is restricted by the corrosive nature of the acidic components of the flue gas, such as oxides of sulphur, nitrogen and carbon, and on trace elements such as vanadium. Usually, the corrosive effect of oxides of nitrogen and carbon present in the flue gases is less severe than that of the oxides of sulphur. Consequently, depending upon the specific application, the lower limit on practical heat recovery is dictated by the following considerations:

- o The dew points of acid gases in the flue gas and the hydrogen content in fuel;
- o The material of construction of the heat exchange equipment and breeching;
- o The energy cost;
- o The capital, operating and maintenance costs of additional equipment such as induced draught fans, pumps, etc.

For example, the lower limit on the temperature of the flue gases from industrial boilers usually ranges between 125°C and 150°C, depending on the fuel. Consequently, a substantial amount of energy is lost in the form of flue gas sensible and latent heat. The latent heat available is significantly greater when natural gas is used as boiler fuel.

Since the early 1970's, several corrosion resistant materials such as special steels, alloys, and high temperature plastics have been tested for application in flue gas handling equipment. The lost sensible and latent heat may be recovered and the efficiency of a boiler plant may be significantly improved by installing a condensing heat exchanger made from these materials.

2.1 Types of Condensing Heat Recovery Systems

There are two basic groups of condensing equipment based on the method of achieving condensation:

* Wet Condensing/Direct Contact
* Dry Condensing/Indirect Contact

A wet condensing type heat recovery system is shown in Figure 2.1. In this type of system the water is sprayed onto the combustion products and the gases and water are in direct contact. To capitalize on higher exit temperatures of the counterflow heat transfer, water is sprayed into the upper part of the unit, to cascade down over baffle plates. Flue gas enters at the base, moving upward against the direction of waterflow. In practice, the exit temperature of water can be as much as 5°C higher than the exit temperature of the flue gases. The base of the unit is a collection tank which overflows continuously, due to the addition of condensate. The collection tank is divided into two parts: the first settles any particulate matter scrubbed from the gases by the spray; the second forms a return circuit reservoir. The second part may be equipped with filters. Acidification of spray water from CO_2 absorption is, in practice, small. If the sulphur content is less than 1 ppm, the circuit components can be made from ordinary steel. Addition of an alkaline compound such as lime could be considered where necessary.

The hot overflow water may be used either directly or as a heat exchange medium in a secondary heat exchanger, depending upon the process conditions.

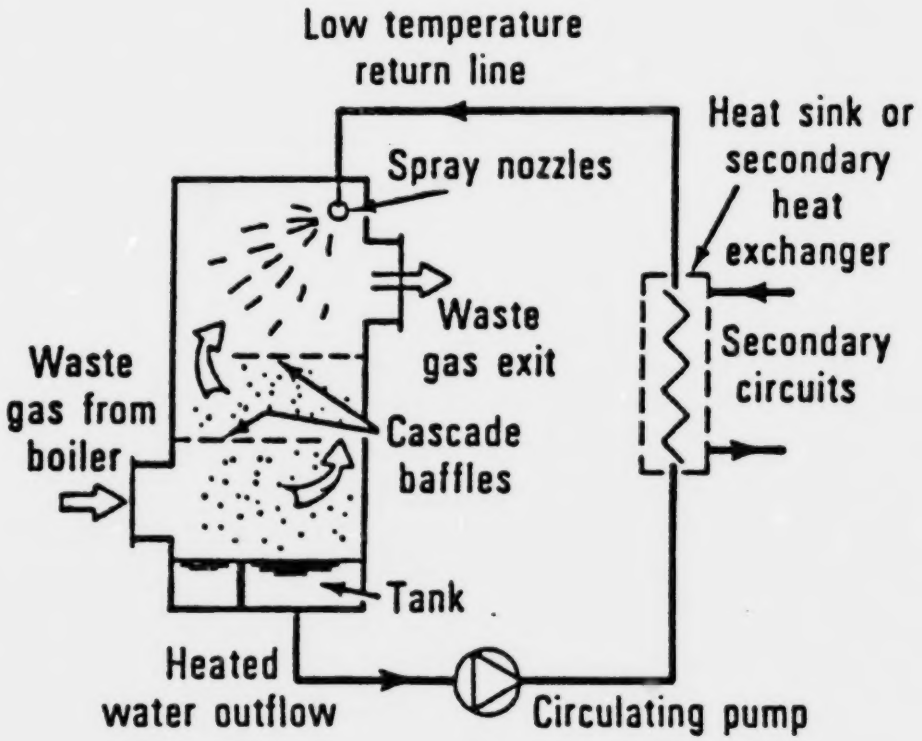

FIGURE 2.1 BASIC SCHEMATIC OF A DIRECT-CONTACT TYPE CONDENSATING HEAT EXCHANGER

The other major types of direct-contact heat exchangers are: bubble-type, packed-column type and sieve-plate type.

The bubble-type direct contact heat exchanger consists of a vertical column having dispersion nozzle for vapour or non-condensible gas entering at the bottom. The inlet for the cold fluid is located at the top. The dispersed gas bubbles up through the liquid, thus effecting the desired heat exchange. Advantages of this system are simple design and construction, and minimal fouling problems. A disadvantage is that excessive back-mixing may occur and decrease heat transfer efficiency.

The packed-column type condensing heat exchanger consists of a column containing a porous supporting plate for the packing material. Although liquid-liquid systems are sometimes encountered, packed columns normally accommodate a gas flowing countercurrent to a liquid. The packing increases the liquid film-gas contact area. Heat transfer occurs between the liquid and gas over the extended interface.

The sieve plate direct-contact heat exchanger, also known as the perforated plate tower, contains a series of plates with holes intended to continually reform the dispersed phase travelling up the column, thus maintaining maximum heat transfer area between the two fluids. It may be used either for a liquid-liquid or gas-liquid heat exchanger. Compared to the bubble-type devices, sieve plate towers have a lower throughput and are more subject to fouling but offer better heat transfer performance. A schematic of a sieve plate exchanger is shown in Figure 2.2.

In the dry condensing type heat recovery equipment, water and gas streams are kept apart in the heat exchanger. The flue gases from the boiler are ducted through one side of the heat exchanger. Boiler feed water or combustion air flows through the

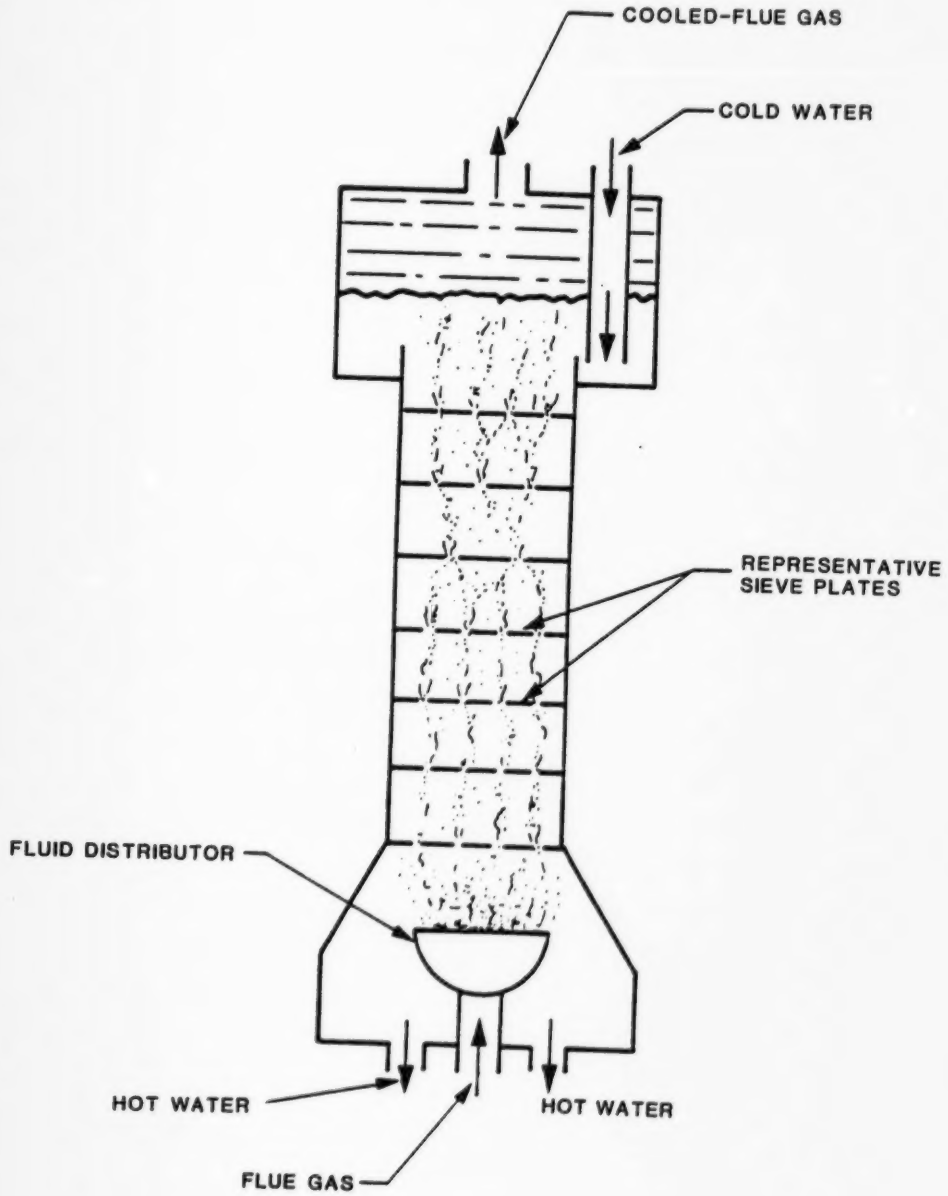

FIGURE 2.2 SIEVE PLATE DIRECT-CONTACT HEAT EXCHANGER

other side and recovers sufficient waste heat to lower the flue gas temperature below the water dew point, thereby recovering a fraction of the latent heat of vaporization. Several types of dry condensing heat exchangers are currently available, their main difference being the material of construction. Teflon coated, stainless steel, copper/aluminum or glass tubes are some of the materials employed to withstand high temperatures and corrosive gases in the condensing heat exchanger.

2.2 Materials of Construction

The materials of construction of waste heat recovery equipment and ducting, breeching etc. which come in contact with the flue gas are specified on the basis of heat transfer rates, temperature and type of heat transfer mediums, pressure, and the composition of the flue gas.

Aluminium, copper or carbon steel are used in low temperature, low pressure applications. For high temperature or high pressure applications stainless steels, special alloys or ceramics are employed. These materials may also find a limited application in a corrosive environment or when the flue gas temperature is below the dew point of the acidic constituents. For these applications, composite materials, speciality plastics, or glass are used to protect surfaces in contact with the corrosive substances.

Laboratory research and field testing have shown that carbon steel alloys such as Corten, Mayari R, HTSO and Yoloy provide adequate protection when the flue gas temperature is above the sulphuric acid dew point. These materials find application in many boiler components and heat recovery equipment. However, such materials do not offer significant resistance to corrosion when the flue gas is cooled below the acid dew point, irrespective of the nature and composition of fuel.

Liquid fuels such as Fuel Oils #6, #4 and #2 contain less hydrogen than gaseous fuels such as natural gas or LPG; thus, flue gases from liquid fuel-fired burners usually comprise less than 5% moisture by volume. The sulphur, nitrogen and trace element content of fuel oils ranges from 1% to 4% by weight; therefore, the acidic gases such as oxides of sulphur and nitrogen (SO_x and NO_x) constitute up to 2.5% of the flue gases. As a result, condensation of flue gases from fuel oils would cause excessive corrosion in equipment made of materials such as carbon steels, aluminium alloys 1100, 5052 and 6061, cupro-nickel alloys 90/10 and 70/30, and aluminized steel. Researchers at Battelle Columbus Laboratories have shown that only stainless steel type 316L and alloy 20 resist corrosion effectively. Type 304 stainless steel also exhibited high corrosion resistance but it did suffer localised pitting.

In gaseous fuels such as natural gas or LPG, the concentration of acidic components is less than 1.0%. However, natural gas comprises more hydrogen than carbon in comparison to fuel oil, consequently water vapour constitute 12-18% of flue gas, when dry air is used for combustion. Therefore, the problem of corrosion due to flue gas containing larger moisture content is likely to be also severe at the same flue gas temperature.

Research on the effect of flue gas from natural gas-fired furnaces has identified stainless steels as the more effective corrosion resistant materials. At the Canadian Gas Research Institute, flue gases from natural gas containing as low as 6.2 milligrams of sulphur per cubic meter of natural gas were used for investigating corrosion characteristics of various metallic and non-metallic compounds. The results indicated that alloys of copper, aluminium, and stainless steel resist flue gas condensates better than carbon steel or lead alloys. The copper alloys showed uniform weight loss unlike aluminium and its alloys which, although more corrosion resistant, suffered pitting at

localized sites. The stainless steel alloys such as 304, 316,317, Nyby T, Nyby MoT and 430 offered greater resistance than either aluminium copper or carbon steel alloys. However, type 430 stainless steel cracked at weld locations. This effect was not observed when a small amount of titanium was alloyed with the type 430 stainless steel. None of the plastic substances tested by CGRI researchers suffered corrosion as a result of flue gas condensation.

These findings have been corroborated by research at American Gas Association Laboratories. The results of testing with condensate from pulse combustion furnaces and boilers led to the conclusion that stainless steel alloys in series 300 and 409, and aluminium alloy 3003 were the most resistive commercially available heat exchanger materials.

The stainless steel series 300 alloys have been successfully utilized in corrosive environments by pulp and paper and chemical processing industries.

In addition to metallic substances, composites or plastic-coated metals may also be used in equipment for flue gas condensation. The application of plastics or plastic-coated metals in flue gas handling equipment is constrained by the plastic softening temperature. Plastics such as teflon perfluoroalkoxy (PFA) and Ryton polyphenylene sulphide can not withstand temperatures higher than 260°C but their ability to resist corrosive substances makes them suitable for flue-gas condensation. However, such engineering plastics cost more than equivalent metals. The lower strength as well as thermal conductivity of such plastics restrict their application. It was found that "shrink-coating" of metal by inserting metal in plastic sleeves and heating to shrinkage temperature produces one of the most stable and corrosion-resistant materials for handling flue gas below 150°C.

Materials such as ceramics and high-strength glass may also be employed in equipment for handling flue gas at temperatures below the acid dew point.

The selection of materials of construction for a flue gas condensing system depends upon flue gas composition and temperature. Based on available literature data, it is apparent that series 300 stainless steels, plastic-coated steel or aluminium alloys, high strength glass and ceramics are best suited for low temperature flue gas handling systems.

2.3 Commercially Available Condensing Heat Recovery Systems

The use of condensing heat exchanger makes it possible to reduce energy consumption by more than 20% in residential applications. Payback periods for such a heat recovery system are typically in the order of one to three years. A number of condensating heat recovery systems are available commercially.

2.3.1 Residential and Industrial Systems

Some of the European residential heating systems are described below:

o Gasunie (the Netherland Gas Institute)

Nederlands Gasunie has developed a design for a 16 kW boiler consisting of a burner and two heat exchangers. The efficiency of the boiler system is raised by 10 to 15%.

In the Gasunie system the hot gases pass upwards through the main fin-tube heat exchanger and then flow downwards through the secondary, bare-tubes condensing heat exchanger. The boiler has an efficiency of 93% for 40°C water return temperature. The pay-back period for the system is of the order of 3-4 years.

o Nefit Turbo

This system is generally located below the roof of the single-family houses. The natural gas burner is placed on the side of the combustion chamber. A centrifugal fan blows the combustion air to the burner through a plastic ducting. The heat exchanger is made of ten aluminium alloy finned tubes inserted between the two cast aluminium plates.

This 18 kW appliance has an efficiency of 86% for 70°C return temperature and a 93% efficiency for a 35°C return temperature. It is equiped with a microprocessor which controls the boiler operation and also indicates the cause of eventual failure.

o Turbopuls

This is an oil or natural gas pulse-combustion device. The combustion chamber and the main heat exchanger are immersed in a water shell whilst the flue-gas condensation occurs in a spiral concentric tubes heat exchanger located above the shell. The elements in contact with the air and flue gases are made of stainless steel. A small fan is used to start the system. Excess air is 1 to 10%. The pressure rise in the combustion chamber makes it possible to connect the exhaust to a 50 mm duct several meters long. The efficiency of the system, is 92% for 6°C return temperature and is 89% for 16°C. The power rating of the system is of the order of 24 kW.

Over and above these, there are a number of residantial systems available in North America manufactured by Lennox Inc., Clare Brothers Inc., O.A. Smith Inc., Ducane Heating Corp., etc. A pulsating combustion type system was developed in Canada and was tested by CCRL/ERL of CANMET, EMR.

o Megasave

The Megasave brand residential space heating furnace systems are designed and manufactured by Clare Brothers, Canada. The systems comprise a natural gas or liquified petroleum gas fired furnace fitted with a stainless steel finned tube heat exchanger for cooling flue gases. An I.D. fan rejects the cooled flue gases at less than 35°C. The cooled flue gas does not require a chimney for venting. The maximum furnace rating is about 35 kW.

Industrial Systems

Two main types of industrial flue gas condensing heat recovery systems are presently available:

o Heat recovery systems with large heat transfer surface areas, eg. finned tube heat exchanger.

o Direct contact heat recovery systems, eg. scrubbers.

Waste heat recovery systems employing a large-heat-transfer-surface heat exchanger of corrosion resistant material are manufactured by several European and North American companies. Some of the representative systems are described as follows:

o Condensagaz Boiler with Condensing Heat Exchanger

Condensagaz is the brand name of a natural gas Boiler developed by Chaudières Guillot, a Groupe Atlantic company from France. The water-wall boiler is constructed from steel alloys. The combustion products are drawn from the combustion chamber into an economizer/heat exchanger at the base of the boiler. From the economizer, a fan type recuperator forces the flue gases through a stainless-steel-alloy condensing heat exchanger at the rear of the boiler. The recuperator preheats combustion air

while the condensing heat exchanger may be used to transfer heat to any medium. A stainless steel or aluminium stack is recommended for use with this sytem since the flue gas temperature could be as low as 35°C.

The minimum power rating is 115 kW and the minimum boiler efficiency is 96% of the dry sensible heat contained in the combustion products (based on the HHV). A schematic of this system is shown in Figure 2.3.

o Deleage DLG 116/C

This system consists of an atmospheric burner and four rows of copper tube heat exchangers. The first one is with bare tubes and the next three are with finned tubes. The air cooled walls of the combustion chamber are made of stainless steel. Power rating is 116 kW and efficiency between 86 and 96%.

o Seccuacier Innorex

Innorex system is based on a patent owned by Gaz de France. In this device the residual heat from the flue-gas is recovered using a direct contact heat exchanger. The heated water is used to heat and humidify the combustion air in another direct contact heat exchanger. By doing this the dew point temperature of the gases is raised to 70°C. The system is made of stainless steel and the power rating ranges between 80 and 400 kW. Efficiency is between 93 to 97% for 70°C to 35°C water return temperature (based on HHV).

o Paquet Thermique Integralgaz

The Intergralgaz is a boiler type water heater made of a fully premixing cylindrical burner and vertical finned copper tubes surrounding it. Combustion products flow radially outwards

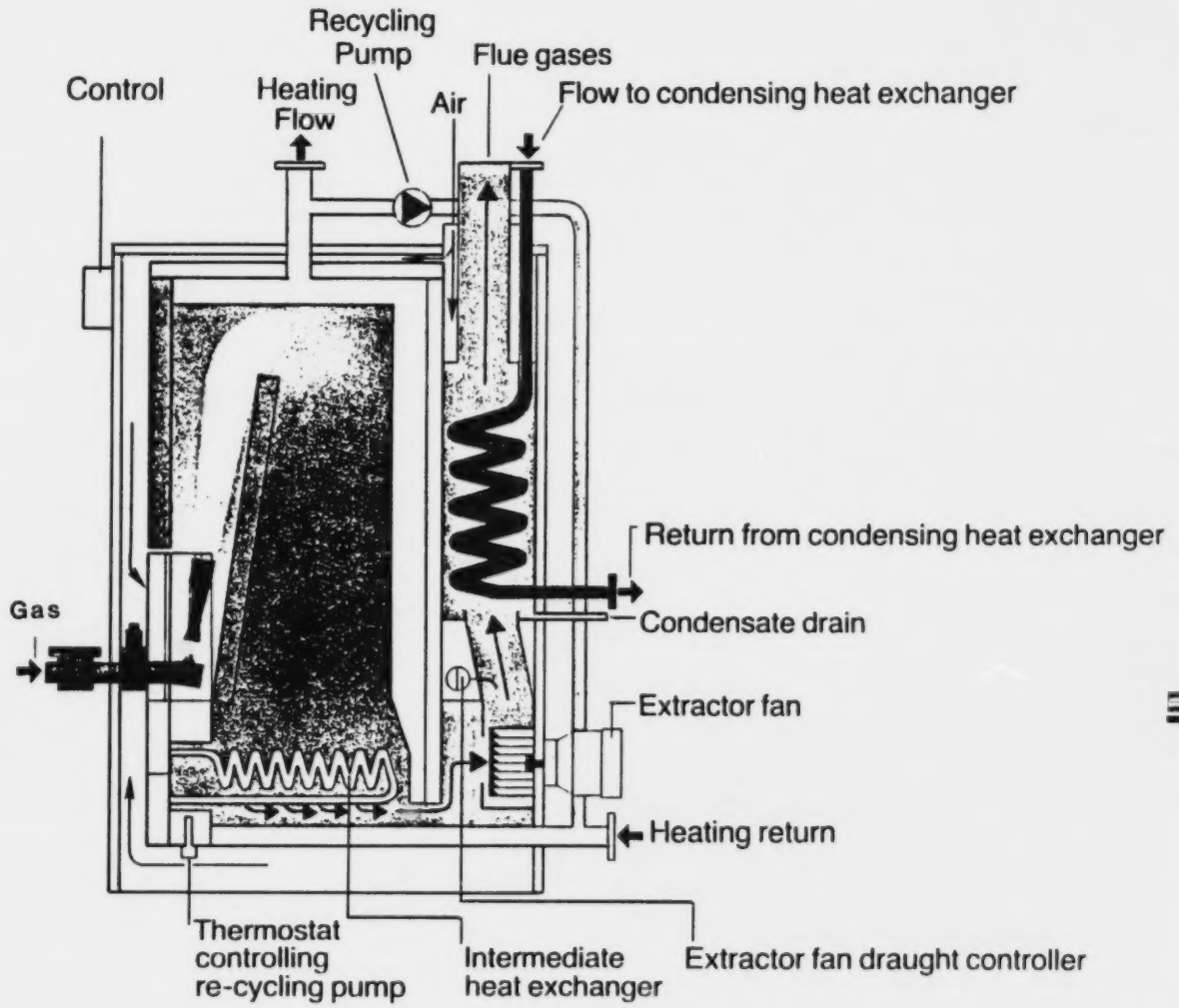

FIGURE 2.3 THE CONDENSAGAZ BOILER

and then back inwards at the lower level where condensation occurs. The power rating is between 70 and 174 kW, and the boiler efficiency is between 81 and 95%.

o Totaleco

The Totaleco system comprises an all stainless steel surface shell & tube heat exchanger which facilitates the recovery of sensible and latent heat in different zones of the heat exchanger. The Totaleco system is manufactured by Chaudières Guillot of France. The single package unit is available in 12 different sizes with capacities ranging between 232 kW and 5815 kW. The standard design pressure is 0.4 MPa. A schematic diagram is given in Figure 2-4.

o Metal Heat Exchanger/Coolers

Several European heat exchanger manufacturers design and sell heat recovery equipment constructed from stainless steel alloys, copper alloys or aluminum alloys. Some of these vendors include I.C. Thermeta B.V. of the Netherlands; Air Froehlich AG fuer Energierueckegewinnung, Switzerland; Danex Holding, Switzerland; Enalco; Van Dijk Heating Incorporated of the Netherlands; Calcol B.V.; and Zantingh Aalsmeer of Switzerland.

The heat exchanger is usually designed with finned-tube metal surface; however, some products are available in bare tube surfaces. Plate type heat exchangers are also manufactured.

Air Froehlich AG also designs and manufacturers glass tube heat exchangers as well as scrubber type flue gas heat recovery/desulphurization systems.

The design specifications for a stainless steel system is included in Appendix F.

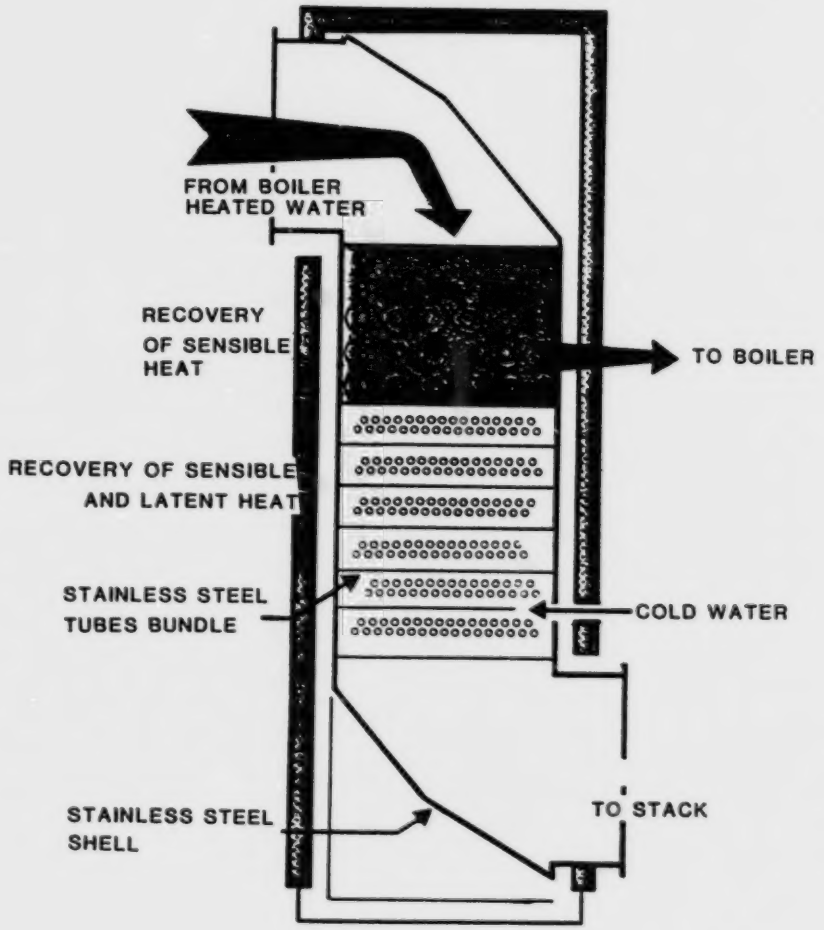

FIGURE 2.4 TOTALECO CONDENSING HEAT EXCHANGER

o Glass Tube Heat Exchangers

In North America, Flue Gas Resources Incorporated of the U.S.A. designs and manufactures flue gas condensation heat recovery systems made of glass tubes. The flue gas temperature is reduced to as low 35°C by preheating air or water. The tubes are made from Kimble KG-33 borosilicate glass tubes while other surfaces contacting the flue gases are made up of synthetic rubber and polymer fiberglass.

The maximum temperature for continuous operation is about 260°C. The specifications are given in Appendix F.

This type of heat exchanger has been used to condense flue gases from large scale power boilers. The payback period is from 1 year to 18 months, depending upon the application.

o Heatmizer

The Heatmizer is a heat exchanger constructed of stainless steels, Cor-Ten steels and aluminium. The minimum flue gas temperature is about 35°C. The heat transfer surface is made up of stainless steel tubing with 3 mm thick aluminium fins that give fins-to-tube surface ratio of about 50:1.

The packaged unit comprises the heat exchanger, soot blower, induced draught fan and exhaust by-pass controls. The condensate is received in a stainless steel drain pan.

When used with natural gas-fired boilers, the gas side pressure drop is only about 25-30 mm W.C. at 150°C gas temperature. The maximum gas inlet temperature is about 325°C.

o CHX System

The CHX system has been developed by Condensing Heat Exchangers Corporation, U.S.A. The packaged unit consists of an induced draft fan, the condensing heat exchanger, fiberglass exhaust plenum and stack, and the required controls and instrumentation. The heat exchanger surfaces are coated with TEFLON Fluorocarbon resin, which is impervious to sulphuric acid corrosive attack at any concentration for temperature range up to 265°C. The exhaust gas passes around the outside of the tubes and the water or air to be heated passes through the tubes. An instrumentation and control package maximizes system efficiency by balancing the heating requirements with the volume and temperature of the exhaust gas available, all within the safe operating range for the particular installation. The system is installed in parallel with the existing stack so that it does not interfere with the primary process.

The heat exchanger is equipped with a water-spray mechanism which can aid in cleaning tube surface and lowering the flue gas temperature below the dew point. The TEFLON coated tube surface promotes a drop-type heat transfer mechanism, which increases the rate of heat transfer, despite the low thermal conductivity of the TEFLON film. The tube covering is carried out by a sleeve-mounting and shrink-coating procedure to ensure uniform unbroken coating surface. The specifications of CHX are included in Appendix F.

The CHX system has been installed on several large scale and small scale power boilers in the U.S.A. and Canada. Payback periods range from 1 to 3 years, depending upon the application.

Some of the direct contact heat recovery systems are described below:

o ICCO-MTCU

This is a vertical cylindrical recuperator. The direct contact between the water droplets and flue gases results in a very efficient heat exchanger. The pressure drop in the system is about 10 to 15 mm of water column. All parts in contact with the flue gas are made of corrosion resistant material such as aluminum, stainless steel or plastics. The water mixed with the condensed products has to be filtered. The payback period of such system is 1 to 2 years, depending on the utilization level of the low temperature heat.

o Mat-Klockner Hydronic

The Hydronic system is designed for gaseous fuel and for power ratings from 11 to 118 kW. About 90% of the heat is transferred to the liquid by direct contact and 10% through the wall and a secondary fluid. All parts in contact with flue-gases and with the heated spray liquid are made of stainless steel. Thermal efficiencies can reach 95%, based on higher heating value (HHV).

o Hanrez Type Condensors

The Hanrez system consists of two heat exchangers: a column type heat exchanger in which the water to be heated is introduced in a fine mist form. The mist settles by passing through the combustion products to a primary water tank. Heat transfer is such that combustion gases are discharged at a temperature only 1°C above that of incoming water.

The second heat exchanger in the Hanrez system is a counterflow, plate fitted heat exchanger which transfers heat between primary and secondary water.

This unique operating system permits combustion and heat transfer in a very small volume. The thermal efficiency ranges from 95 to 97%, with rated power of 2 to 290 kW. All components which come in contact with primary water and combustion by-products are made of stainless steel. Corrosion and scale build-up are thus inhibited.

The systems described in this section are representative of the types of condensing heat exchangers available in Europe and North America. Nonetheless, the list is not exhaustive and not all systems are suitable for the application considered in the study.

3.0 FACILITY DESCRIPTION

3.0 FACILITY DESCRIPTION

Paper Mill

The Domtar Fine Papers Mill at Cornwall, Ontario is one of the largest integrated pulp and paper mills in Canada. The mill produces an average of 450 tonnes per day of bleached hardwood kraft pulp, all of which is used for making an average 755 tonnes per day of fine grade paper. Annually, the mill generates and consumes 1 930 000 tonnes of steam and pumps about 113 600 000 cubic meters of fresh water from the Cornwall Canal.

The mill consumes about 250 000 tonnes of "oven-dry" wood, of which about 40 percent is purchased as chips and the rest is received as logs. The logs are chipped in the Woodroom, consisting of two barking drums and a chipper. The wood is processed to form pulp in six batch-type wood-digesters. Liquor is concentrated in multiple effect evaporators. A 5-stage bleach plant is used to produce bleached hardwood-pulp.

All of the kraft pulp produced by the plant is converted to fine grade paper in six paper machines. The mill also buys more than 3000 tonnes of pulp per month from Domtar's mills in Québec. The products from paper machines are conveyed to the finishing and storage section.

The mill is equipped with a 275 tonnes-per-day chemical and waste heat recovery boiler. During the early stages of this study the recovery section of the plant also included a 185 t/d Copeland fluidized-bed reactor for processing the black liquor, and a fluidized-bed lime calciner for recausticizing process.

A general layout of the mill is shown in Figure 3-1.

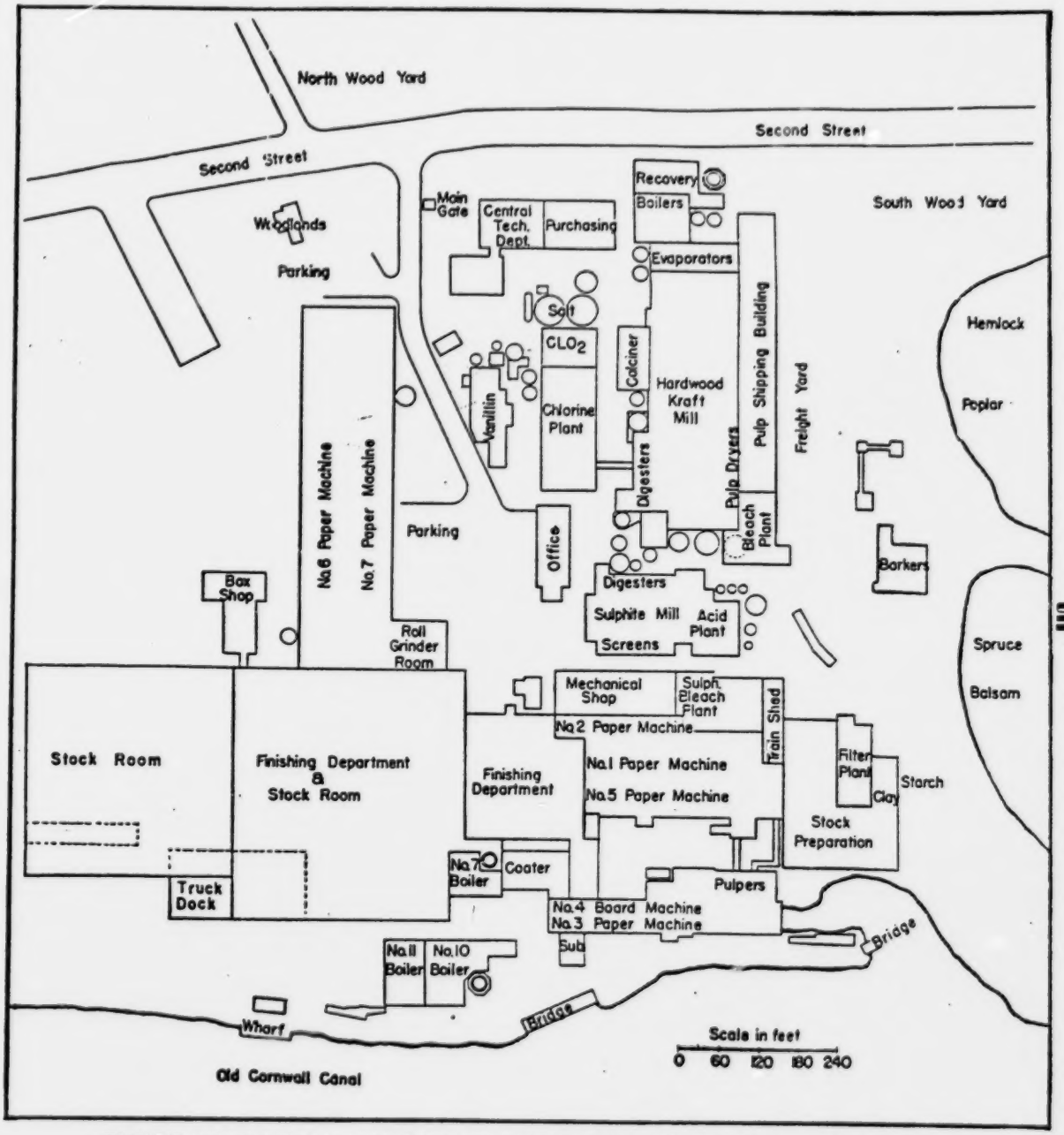

FIGURE 3.1 GENERAL LAYOUT OF DOMTAR FINE PAPERS MILL, CORNWALL

3.1 Steam Generation Section

The kraft process and the paper machines both require large quantities of steam and power. The manufacture of hardwood unbleached pulp by the kraft process requires about 3700 kg steam per tonne of pulp and each of the paper machines need an average of 3000 kg steam per tonne of product. On average, the Cornwall plant consumes 5 411 000 kilograms of steam per day.

The steam generation section of the mill comprises two Babcock and Wilcox power boilers (#10 and #11). Additional steam is generated in the recovery boiler. About 60 to 65 percent of the steam required by the mill is supplied by the main power boiler (#11) and about 30 percent by the recovery boiler (#12). The smaller power boiler (#10) is operated in stand-by mode. The boiler ratings are given in Table 3-1.

3.1.1 Main Boiler and Auxiliaries

The main power boiler is a Stirling two-drum single-pass boiler built by Babcock-Wilcox and Goldie-McCulloch in 1959. The design specifications for this boiler are given in Appendix A: Tables A-1 and A-2. At present, the main boiler is fired with natural gas, using six natural gas burners mounted on the boiler furnace. Nevertheless, it is possible to use either gas, liquid or solid fuels by changing the burners installed on the furnace.

Combustion Air

Combustion air is supplied by two forced draught fans made by Canadian Sirocco. The specifications for these units are given in Appendix A: Table A-3.

TABLE 3-1 BOILERS INSTALLED AT DOMTAR FINE PAPERS MILL IN CORNWALL, ONTARIO

BOILER NUMBER #	SUPPLIER	STEAM CAPACITY kg/h	FUEL
10	Babcock-Wilcox & Goldie-McCulloch	76 500	Natural Gas/Oil
11	Babcock-Wilcox & Goldie-McCulloch	160 000	Natural Gas/Oil
12*	-	76 500	-

* Chemicals and heat recovery boiler.

Boiler Controls

The combustion air supplied to the boiler is controlled by a standard carbon monoxide trim mechanism, which controls the variable vanes in the double inlets on the F.D. fans. The F.D. fans are also equipped with single outlet louvre shut-off dampers. The flue gases leaving the air heater are monitored by an online measurement device manufactured by Econics. The concentration of various combustion products, CO, CO_2, O_2, hydrocarbons and particulates, is measured. The CO level in the flue gas stream is the basis for Econics microprocessor-based automatic boiler control system.

3.1.2 Heat Recovery Air Heater

The boiler is equipped with an air heater to recover some of the energy in the combustion products. The design specifications for the air heater are given in Appendix A: Table A-4. The flue gases are drawn through the air-heater by an induced draught fan, the specifications for which are given in Appendix A: Table A-5. Two steam-coil air preheaters are located in the ducts between the forced draught fans and the air heater to prevent corrosion resulting from condensation, due to low load operation or from burning sulphur-containing fuels. Both the air preheaters have the capacity to heat about 160 000 kilograms of air per hour from -7 °C to 62 °C when supplied with saturated steam at 1379 kPag.

3.2 Energy Cost

The fuel cost for treating and heating the water to generate the required steam is about 15 000 000 dollars per annum. Thus, optimizing the efficiency of fuel-to-steam conversion and

minimizing the loss of energy in the flue gases are areas of prime concern at this plant.

A pulp and paper mill produces several waste gas streams which carry large amounts of low and medium grade heat. Recovery of energy from these sources could improve the thermal efficiency of the plant and lower the fuel costs. As mentioned in Section 3.0, the Cornwall mill recovers some of the waste energy in the Recovery Boiler and the combustion air heater. In 1980, the mill instituted an energy conservation project. As a result, waste energy amounting to about 74 Giga-Joules per hour was recovered from the Recovery Boiler exhaust gases. The Copeland fluidized-bed reactor for black liquor recovery was also equipped with plate-and-frame heat exchangers to recover about 31 Giga-Joules per hour by heating boiler feed water make-up. Recently however, the Copeland reactor was taken out of service due to its high maintenance and down-time record. This has increased the fuel costs.

The costs incurred in installing an energy conservation system based on flue gas condensation principles could be recovered in an acceptably small time span if the system delivers at least a 4% improvement in thermal efficiency. Such a system would reduce stack losses and offset fuel costs incurred in heating boiler feed water make-up or process water.

This site offers an excellent opportunity to assess the energy conservation potential of flue gas condensation systems for large industrial boilers.

4.0 DEVELOPMENT OF DESIGN CRITERIA FOR WASTE HEAT RECOVERY SYSTEM

4.0 DEVELOPMENT OF DESIGN CRITERIA FOR WASTE HEAT RECOVERY SYSTEM

The heat recovery system on the main power boiler at Domtar Fine Papers Mill, Cornwall, Ontario comprises an air heater which raises the temperature of combustion air from ambient to about 245°C (see specifications in Appendix A).

During normal operation, flue gases exiting the air heater are at an average temperature of 147-149°C. At these temperatures the flue gases carry both the sensible heat and the latent heat of vaporization of water formed by combustion of hydrogen in the fuel. The boiler is usually fired with natural gas, hence the flue gases have substantial latent heat content.

To determine the availability of sensible and latent heat in the waste gases, it is essential to determine the composition of flue gases and the range of operating conditions for the boiler. Therefore, site tests were carried out on October 16th, 1985 to gather data on the hot gases discharged from Boiler #11. The standard test procedures are presented in brief in Appendix B. The flue gases were analysed using these procedures. The results are also summarized in Appendix B.

The operating data for Boiler #11 were obtained from the records of daily boiler plant operations provided by Domtar.

The natural gas composition was obtained from fuel analyses received by Domtar. The fuel flow rate was determined from monthly steam generation and fuel consumption reports. The heating value of the fuel was calculated from the heating value of individual components.

The range of summer and winter steam generation rates were calculated from daily strip-chart records for a twelve month period.

Combustion air and boiler feed water make-up conditions were provided by Domtar staff.

The data gathered from Domtar's records and site tests were used to calculate boiler efficiency and determine the energy content of the flue gases. The boiler efficiency and heat loss calculations are included as Appendix D of this report.

In making the boiler efficiency calculations, the flue gas composition at the air heater outlet was used to determine the amount of air supplied to the furnace. As given in appendix D, it was found that the boiler is operated with 18% excess air. The boiler efficiency was calculated to be 82%. However, as the flue gas composition data in Appendix B indicates, there is considerable difference in the oxygen and carbon dioxide concentrations at boiler outlet, air heater inlet and air heater outlet.

These variations in oxygen content and excess air were discussed with the plant personnel. It was suggested that as the boiler was undergoing some maintenance work these might have resulted from leakages in the flue gas path.

They had not noticed any air leakage in the flue gas path before the commencement of the maintenance work.

The energy which may be recovered by condensing flue gas is low temperature thermal energy. The utility value of the low temperature heat plays a major role in determining the potential of applying a flue gas condensation heat recovery system. Since the utility of recovered waste heat is site-specific, both the existing and planned environment of the plant are of importance in developing design criteria for a retrofit equipment. Therefore, the design criteria given in Appendix E, and Table E-1 and Table E-2 were developed with inputs from Domtar personnel.

Preheating boiler feed water make-up stream or heating combustion air are two main modes of direct utilization of recovered low temperature energy. Other applications include heating process water or generating either hot water or hot air for space heating.

Boiler #11 is equipped with a combustion air heater which reduces heat losses and lowers the flue gas temperature to about 150°C.

The plant had been recovering waste energy from the fluidized bed Copeland black liquor reactor and the Recovery Boiler (Boiler #12), which is equipped with a peabody scrubber. This energy was utilized to heat the boiler feed-water make-up stream and the condensate from various areas of the plant. As a result, there did not exist any direct mode of utilizing low temperature heat from the Boiler #11 flue gas.

Initially it was found that the plant needed a source of energy to heat about 18 900 kilograms per minute of process water from about 60°C to about 71°C. The inlet temperature has since been changed to 26°C as the other sources of waste energy can provide heat at a higher temperature than the boiler #11 flue gas.

An examination of some of the preliminary designs showed that the proposed designs would not be able to meet the requirements of the plant since, at the suggested water flow rate, the temperature of the process water could be raised at most by 5°C.

Since the only practical means of elevating the outlet temperature of process water was to reduce the water flow rate, the vendors were requested to submit revised designs. The design criteria for revision are given in Table E-1.

During the course of discussions with Domtar personnel it was learnt that the fluidized bed Copeland black liquor reactor had been shut down on December 1, 1985 due to maintenance problems and a lack of availability of spare parts. Consequently, the plant had to consider alternate sources of energy to heat boiler feed water make-up stream. The feed water to Boiler #11 comprises between 70% and 81% fresh make-up water (see Appendix C).

As mentioned above, heating of boiler feed water or combustion air are the most promising applications of boiler heat loss reduction equipment. These applications deliver direct and measurable energy savings with a minimum of retrofit expenses. Both the amount of flue gas produced and the boiler feed water make-up are proportional to the steam generation rate. Thus, the flue gas flow rate through a condensing heat exchanger would be matched by the make-up water flow rate. In addition, the recovered energy is utilized within the boiler environment; therefore, the retrofit work is localized.

In comparison, heating of process water or space heating applications require greater retrofit effort as well as expense.

Therefore, to ascertain the maximum potential of a flue gas condensing systems for application with large industrial boilers, the design criteria for condensing heat recovery equipment for Boiler #11 were revised as shown in Table E-2.

5.0 EVALUATION OF DESIGNS OF A FLUE GAS CONDENSING HEAT RECOVERY SYSTEM

5.0 EVALUATION OF DESIGNS OF A FLUE GAS CONDENSING HEAT RECOVERY SYSTEM

Identification of Vendors

The recovery of low temperature thermal energy by cooling stack gases below the dew point requires special materials of construction for surfaces which come into contact with the colder flue gas. The capability to process special materials of construction determines the capability of a manufacturer to provide a system for a given application. The commercial systems available in North America and Europe were discussed in Section 2.0. To establish the potential of applying these systems for heat recovery from Boiler #11, the vendors of the systems were contacted in the early stages of the study. A list of vendors contacted and their responses is given in Table 5-1. Since replies from some of the vendors were not received at this early stage, they were re-contacted once the design criteria were developed.

5.1 Preliminary Designs for Condensing Heat Exchangers

The design criteria given in Appendix E and the first revision comprising changes in the inlet conditions of the heat recovery medium were sent to those vendors who indicated a capability to provide flue gas condensation systems for industrial boilers. The names of these vendors and their responses are given in Table 5-2 through Table 5-6.

Groupe Atlantic of France indicated their inability to either design or manufacture a condensing heat exchanger to suit the application being considered. They are only vendors of a standard product called "Totalco" which was described in Section 2.0. The maximum rating for this condensing heat exchanger is 5.8 MW.

TABLE 5-1 LIST OF VENDORS CONTACTED FOR FLUE GAS CONDENSING HEAT RECOVERY SYSTEMS

NUMBER	VENDOR NAME	VENDOR'S RESPONSE
1	Air Froehlich AG, Switzerland	Glass & metal systems for large/small boilers
2	American Shack Company, U.S.A.	Products not suitable for condensing application
3	Atlantic Groupe, France	Stainless Steel systems for large/small boilers
4	Baxi Heating, U.K.	No reply
5	Berner International Corporation, USA	Products not suitable for application being considered
6	Calcol B.V., The Netherlands	Metal systems for large/small boilers
7	Canadian Recuperators, Canada	Application for high temperature Power Plant waste gases
8	CETIAT, France	No reply
9	Claire Industries, Canada	Residential boiler applications, space heating units
10	Condensing Heat Exchanger Corporation, USA	Teflon-coated copper alloy systems for all applications
11	Crane Company, U.S.A.	Products not suitable for application being considered
12	Danex Holding AG, Switzerland	Range of products for industrial applications
13	Dibar Engineering and Sales, Inc., Canada	Canadian Representative for Condensing Heat Exchanger Corp.
14	Enalco B.V., The Netherlands	No reply
15	Fagersta AB, Sweden	No reply
16	Flue Gas Resources, U.S.A.	Glass tube systems for large/small boilers
17	Fonderies Franco-Belges, France	No reply
18	Heatmizer Incorporated, U.S.A.	Stainless Steel systems for large/small boilers
19	I.C. Thermeta B.V., The Netherlands	Metal systems for large/small boilers
20	Intertherm, Inc., U.S.A.	Residential boiler applications, space heating units
21	Lennox Industries Incorporated, Canada	Residential boiler applications, space heating units
22	McCarthy & Robinson, Canada	Gas-to-Gas recuperators only. Not suitable for Condensing
23	OTB Particlpazioni, Italy	Metal systems for large/small boilers
24	SeraHusson, France	No reply
25	Solar Turbines Incorporated, USA	Application for high temperature waste gases only
26	ASEA - STAL AB, Sweden	Heat pump applications - Canadian suppliers also
27	Studsvik Energiteknik AB, Sweden	No reply
28	Thermal Transfer Corporation, USA	Application for high temperature Power Plant waste gases
29	Thorn EMI Heating Limited, U.K.	Does not make systems for such applications
30	RHOSS, Italy	No reply
31	Van Dijk Heating B.V., The Netherlands	Range of products for industrial applications
32	Zantingh Aalsmeer AG, The Netherlands	Canadian Representative in B.C. and Ontario

TABLE 5-2 VENDORS' REPLIES TO REQUEST FOR QUOTATIONS FOR A FLUE GAS CONDENSING SYSTEM FOR BOILER #11

NUMBER	VENDOR NAME	VENDOR'S RESPONSE
1	Air Froehlich AG, Switzerland	Specified Stainless Steel Heat Exchangers
2	Atlantic Groupe, France	No Bid, Application Too large
3	Calcol B.V., The Netherlands	No Bid, Can't meet North American Standards
4	Danex Holding AG, Switzerland	No Reply
5	Dibar Engineering and Sales, Inc., Canada	Specified a CHX Systems
6	Flue Gas Resources, U.S.A.	Specified a Glass Tube System
7	Heatmizer Incorporated, U.S.A.	No Bid, Application Too Large
8	I.C. Thermeta B.V., The Netherlands	Specified a Battery of Metal Heat Exchangers
9	OTB Particpazioni, Italy	No Bid, Application Too Large
10	Van Dijk Heating B.V., The Netherlands	No Bid, Application Too Large

Three other vendors, Heatmizer Inc. of U.S.A., OTB Particpazioni of Italy and Van Dijk Heating B.V. of the Netherlands responded similarly.

Heatmizer, Inc., Kansas, U.S.A. which designs and supplies a condensing heat exchanger made from stainless steel alloy tubes with aluminium fins for industrial boilers was unable to design or manufacture a system which would meet the design criteria. The largest "Heatmizer" unit is designed to operate with boilers generating 11.8 MW of steam energy.

OTB Particpazioni of Italy which had indicated the possibility of adapting their design of a condensing heat exchanger for residential boilers to meet industrial requirements replied that the application being considered was too large for their systems.

Van Dijk Heating, Inc. of the Netherlands were also unable to provide a design for such a large scale industrial boiler. The largest condensing heat exchanger designed and manufactured by Van Dijk is for application with a 20 000 kilograms-steam-per-hour boiler.

Zantingh Aalsmeer B.V. of the Netherlands indicated that they have representatives in Canada who might be able to respond to our request for quotations. However, the information provided by Zantingh was insufficient and their representatives in Ontario or British Columbia could not be contacted.

Air Froehlich AG, Switzerland, Dibar Engineering and Sales Inc., Pointe Claire; I.C. Thermeta, the Netherlands; and Flue Gas Resources of the United States responded by submitting designs based on either on the original set of design criteria (see Appendix E) or on the revised criteria (see Table E-1). Only Flue Gas Resources developed designs for both sets of conditions.

The design specifications and anticipated energy savings provided by the vendors are given in Tables 5-3 through 5-6. Only the designs based on the revised criteria are included.

I.C. Thermeta B.V. of the Netherlands responded only to the original request for bids. As mentioned in Section 2.0, I.C. Thermeta designs and manufactures aluminium and stainless steel condensing heat exchangers. They considered the boiler capacity of 175 800 kilograms-steam-per-hour to be too large for a single condensing heat exchanger. In their view the design of a metal heat exchanger for cooling about 200 000 kilograms of flue gas per hour would be unsafe due to the likelihood of excessive stress at weld joints. Hence, I.C. Thermeta specified a battery of twelve flue gas condensors made up of aluminium alloy 51 S and 57 S or of stainless steel.

The specified battery of heat exchangers would recover a total of 16.743 Giga-Joules per hour and raise the temperature of 1 140 000 kilograms per hour of process water from 60°C to about 63.5°C. The flue gas temperature would drop from 149°C to about 65°C.

The heat transfer area of each unit would be about 384 square meters. If aluminium was selected to be the material of construction the battery would cost a total of 348 000 guilders (i.e. 177 480 Canadian Dollars at 0.51$Cdn/Guilder). If stainless steel was required the cost would amount to 492 800 Guilders (Cdn$251 328). Auxiliary equipment including 12 pumps, centrifugal fans, motors, valves, flanges, a control panel would cost about 190 100 Guilders (Cdn$96 951). All the prices are F.O.B. Naaldwijk, the Netherlands and the Canadian dollar rate is based on mid-day quote for January 10, 1986. In the request-for-quotations, the vendors were allowed the freedom to assume larger water flow rate if additional energy was available and recoverable.

TABLE 5-3 PREDICTED PERFORMANCE FOR FLUE GAS CONDENSING HEAT EXCHANGERS FOR HEATING PROCESS WATER

(WINTER CONDITIONS)

VENDOR DESIGN PARAMETERS	CHX	FGR	AFR
FLUE GAS SIDE			
Flow Rate, kg/h	185 452	158 755	140 000
Inlet Temperature, °C	148.9	146.67	147
Outlet Temperature, °C	63.5	51.1	51
Pressure Drop, mm W.C.	120.65	122.43	11.22
BOILER FEED WATER SIDE			
Flow Rate, kg/h	90 850	108 860	205 600
Inlet Temperature, °C	7.2	18.9	26.0
Outlet Temperature, °C	71.1	71.6	43.0
Pressure Drop, kPag.	34.89	58.54	10.00
ENERGY RECOVERED			
Sensible Heat, MJ/h	17 683.1	-	-
Latent Heat, MJ/h	6 568.7	-	-
Total Heat, MJ/h	24 251.8	24 012.8	14 630.4

Notes: The vendors included in Tables 5-3 to 5-10 are as follows:

CHX - Condensing Heat Exchanger Corp., U.S.A.
FGR - Flue Gas Resources Inc., U.S.A.
AFR - Air Froehlich AG fuer Energierueckgewinnung, Switzerland

TABLE 5-4 PREDICTED PERFORMANCE FOR FLUE GAS CONDENSING HEAT EXCHANGERS FOR HEATING PROCESS WATER

(SUMMER CONDITIONS)

VENDOR DESIGN PARAMETERS	CHX	FGR	AFR
FLUE GAS SIDE			
Flow Rate, kg/h	137 452	113 396	98 000
Inlet Temperature, °C	148.9	146.67	147
Outlet Temperature, °C	56.0	52.4	42
Pressure Drop, mm W.C.	68.83	117.86	21.41
BOILER FEED WATER SIDE			
Flow Rate, kg/h	90 850	79 377	205 600
Inlet Temperature, °C	7.2	32.2	26.0
Outlet Temperature, °C	71.1	78.33	39.0
Pressure Drop, kPag.	34.54	31.99	10.00
ENERGY RECOVERED			
Sensible Heat, MJ/h	14 259.3	-	-
Latent Heat, MJ/h	9 844.5	-	-
Total Heat, MJ/h	24 103.8	15 315.4	11 187.9

Note: See Table 5-3 for vendor names.

TABLE 5-5 CONDENSING HEAT EXCHANGER SPECIFICATIONS FOR HEATING PROCESS WATER

VENDOR	CHX	FGR	AFR
Tube Side Fluid	Water	Water	Water
Tube Material	Teflon Coated Copper Alloy 706	Borosilicate Glass KG-33	Stainless Steel AISI 304
Number Passes on Tube Side	-	-	2
Units	1	1	2
Total Heat Exchange Area in Square Meters	1 553.62	-	770
Height, cm	510.24	464.82	80.0
Depth, cm	618.74	271.78	574.5
Width, cm	274.32	226.06	146.0
Dry Weight, kg	23 398	8 023	5 000
Wet Weight, kg	32 942	11 425	7 450

Note: See Table 5-3 for vendor names.

TABLE 5-6 COMPARISON OF CONDENSING HEAT EXCHANGERS DESIGNS FOR HEATING PROCESS WATER

VENDOR	CHX	FGR	AFR
SAVINGS			
Heat Recovery Rate (avg.), MJ/h	24 177.80	19 664.10	12 909.15
Annual Fuel Savings, GJ	207 929.08	169 111.26	111 018.69
Fuel Cost, $/GJ	4.05	4.05	4.05
Total Savings, $Cdn/y	842 113	684 901	449 626
HEAT EXCHANGER COST			
in Canadian Dollars	643 453	444 680	230 690
in $/(GJ-Saved-per-Year)	3.09	2.63	2.08

Notes:

1. See Table 5-3 for vendor names.

2. Heat Exchanger costs are C.I.F. Montreal with 15% for taxes.

I.C. Thermeta suggested the use of a second battery of 12 condensing heat exchangers to reduce the flue gas temperature to about 40°C to recover an additional 29.3 Giga-Joules per hour. this amount of energy would heat an additional 700 000 kilograms per hour of cooler process water from 30°C to about 40°C. This would increase the amount of energy recovered from flue gases to about 46.044 Giga-Joules per hour. The total cost including auxiliaries would then be 1 230 450 Guilders ($Cdn 627 530).

The use of certain aluminium and stainless steel in flue gas condensing equipment is not highly desirable due to corrosion and pitting problems (see Section 2.0). Installation cost for such a battery of units would be significantly higher than that of a single unit. The operating and maintenance costs would also be marginally higher with such a large number of heat exchangers.

However, the major advantage of such a system would be greater than 95% system availability due to the modular approach.

I.C. Thermeta claims that it has installed more than 350 such units in Europe. I.C. Thermeta has indicated that most of the units have met performance requirements of the users. The firm guarantees its products for a period of two years.

Since I.C. Thermeta did not submit a revision to their designs, their design was not included in Tables 5-3 through 5-6.

Air Froehlich AG fuer Energierueckgewinnung, Switzerland has specified the use of two condensing heat exchangers connected in parallel to heat 205 600 kilograms per hour of process water. The heat exchangers would have 770 square meters of total heat transfer surface to deliver a total of 17.212 Giga-Joules-per-hour at maximum flue gas flow rate of 175 000 kilograms per hour. As given in Tables 5-3 and 5-4, the energy savings would

average about 11.188 Giga-Joules-per-hour under summer conditions, 14.631 Giga-Joules-per-hour under winter conditions and 12.909 Giga-Joules-per-hour, annually.

The process water would reach a maximum of 57°C and the annual average would be about 41°C. The maximum operating temperature on the water side would be limited to 95°C.

The maximum pressure drop on the flue gas side would be 320 Pa at a winter condition maximum flow rate of 175 000 kilograms flue gas per hour.

The design calls for downward flue gas flow if the boiler is operated with both natural gas and fuel oil. Flue gas flow may be upward if the boiler is fired only with natural gas. The water flow diagram would be opposite to that of the flue gas. A schematic diagram of the unit is given in Figure 5-1.

The total cost of the heat exchangers, including transportation and freight insurance up to Montreal, is Swiss Francs 295 000.00 (200 600 Canadian Dollars at Cdn $0.68/Swiss Franc). Air Froehlich does not supply any auxiliary equipment with the heat exchangers. The products are guaranteed for a period of a year from installation date but no more than 15 months from shipping date. The terms and conditions of the warranty are given in Appendix G.

Dibar Engineering and Sales, Inc. of Pointe Claire, Quebec is vendor of CHX brand condensing heat recovery systems designed and manufactured by Condensing Heat Exchanger Corporation, U.S.A. The CHX system has already been described in Section 2.0. During the rest of the discussion the system would be referred to by its brand name CHX. The CHX system is schematically shown in Figure 5.2.

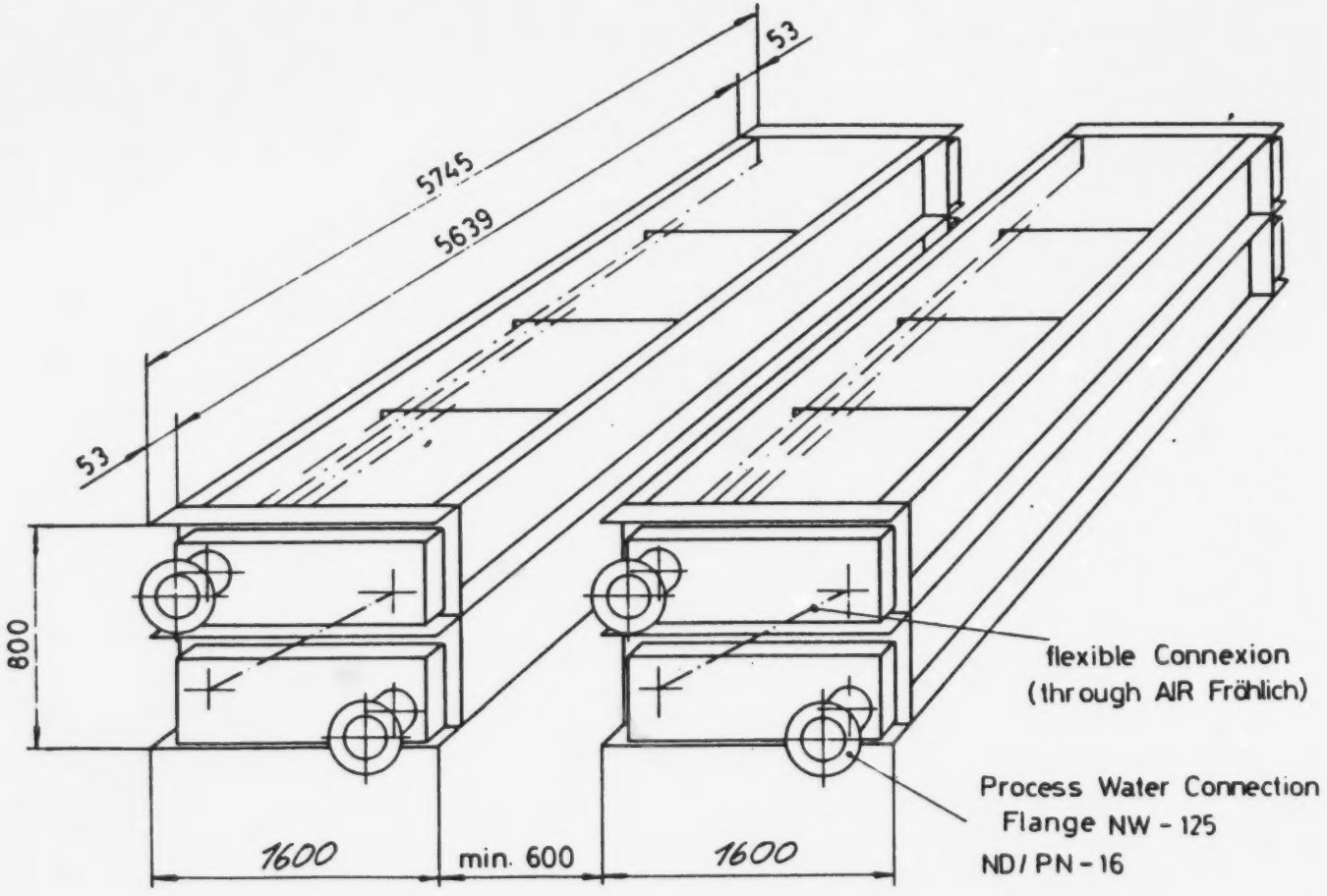

FIGURE 5.1 STAINLESS STEEL TUBE HEAT EXCHANGER BASED ON AFR DESIGN FOR BOILER NO. 11

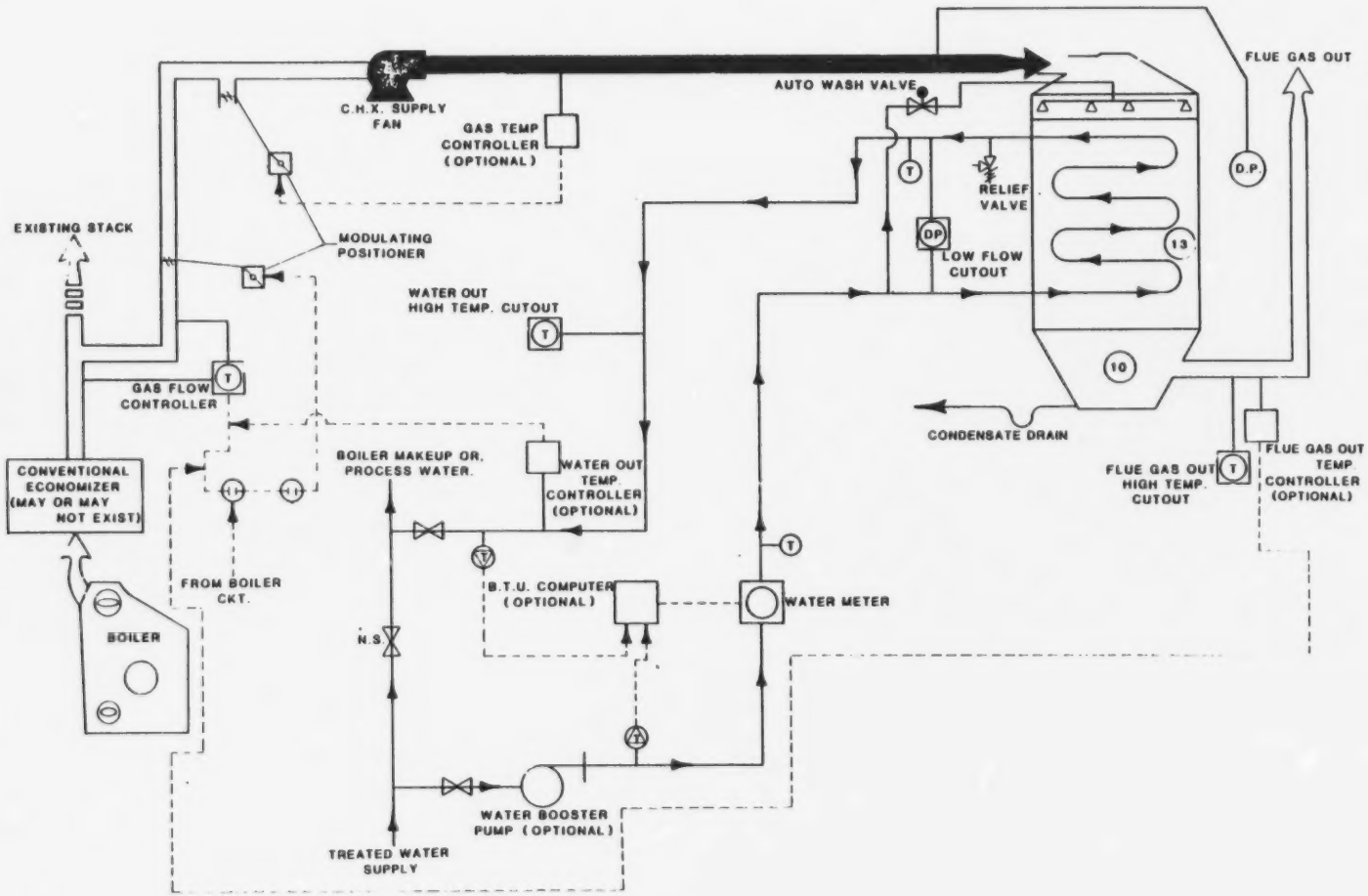

FIGURE 5.2 SCHEMATIC OF THE CHX SYSTEM

Condensing Heat Exchanger Corporation has submitted a design based on a combination of design conditions given in Appendix E and Table E-1. The specified system would reduce stack losses and recover an average of 24.178 Giga-Joules-per-hour. The recovered energy would heat 90 847 kilograms-per-hour of process water from 7.2°C to 71.1°C. The flue gas pressure drop across the heat exchanger would be about 120.65 mm W.C. and the flue gas pressure drop across the plenum, duct and breeching would be about 22.86 mm W.C. Figure 5.2 schematically represents the CHX system.

The heat exchanger would have about 1553.6 square meters of teflon coated copper tube heat transfer area. The heat exchanger would cost US$398 853.00 (558 394 Canadian Dollars at a rate of Cdn$ 1.40/U.S. Dollar). The auxiliaries supplied by the vendor cost a total of US$ 133 966.00 (Cdn$ 187 552). The list of auxiliaries and the vendor's warranty are included in Appendix G.

A unique feature of the vendor's warranty is that the vendor would reimburse the client for any shortfall in rated annual energy savings when the unit is operated at design conditions. All prices are Freight-On-Board Warnerville, New York, U.S.A.

Flue Gas Resources, Incorporated has submitted designs for both the original design criteria and the modified criteria. The vendor proposes a borosilicate glass tube heat exchanger to reduce stack losses and heat process water.

The design based on the first set of criteria specifies that the heat exchanger would recover an average 17.345 Giga-Joules-per-hour to heat 680 337 kilograms per hour of process water at 26.7°C. The water outlet temperature would reach 32.8°C and the flue gas temperature would be reduced to 48.9°C.

The cost of the heat exchanger would be about US$ 197 040.00 (i.e. 275 856 Canadian Dollars. An optional automatic wash system can be installed on the heat exchanger to provide a means of cleaning tube surfaces when the boiler is fired with fuel oil or coal. The cost of the wash system would be US$6101.00 (i.e., Cdn$ 8541). The vendor would also supply a control panel which includes a temperature protection for the glass tube exchanger. The cost of system control panel and other ancillaries is US$4430.00 (Cdn $ 6202). All the prices are quoted Freight-On-Board Toledo, Ohio. The products are covered by one year warranty from the first day of operation or eighteen months from the date of delivery. The warranty is included in Appendix G.

In response to the first request for revision (Table E-1), Flue Gas Resources designed a glass tube heat exchanger that would recover an average of 24.013 Giga-Joule-per-hour in winter and 15.315 Giga-Joule-per-hour in summer. The recovered energy would heat 108 860 kg/h of process water in winter and 79 377 kg/h of process water in summer. The flue gas side pressure drop at average winter condition is specified to be 122.43 mm W.C. while the water side pressure drop would reach a maximum of 58.53 kPag.

The heat exchanger would cost US$275 000 (Cdn $ 385 000), the automatic wash system US$7518.00 (Cdn$ 10 525) and other auxiliaries would cost $4430.00 (Cdn$ 6202).

The designs submitted by Flue Gas Resources, U.S.A. Dibar Engineering and Sales Inc., Canada, and Air Froehlich of Switzerland may be considered competitive and suitable for the Boiler #11.

The design by I.C. Thermeta was not considered as suitable as the designs submitted by these three vendors, since the I.C. Thermeta design called for a battery of 12 aluminium heat exchangers. As discussed in Section 2.0, the use of aluminium is not acceptable in condensing heat exchangers because of its susceptibility to corrosion and pitting attack from acidic components in flue gas. Additionally, the installation, operation and maintenance cost of a battery of heat exchangers is higher than that of a one or two unit system.

5.2 Condensing Heat Exchangers for Heating Boiler Feed Water Make-Up

Prior to comparing the merits of each of the three designs presented in Tables 5-3 through 5-6, discussions were held with Domtar personnel to ascertain their views on the various types of system. The discussions led to a second revision in the design criteria as mentioned in Section 4. The revised design criteria given in Table E-2 were transmitted to Air Froehlich, AG, Dibar Engineering and Sales, and Flue Gas Resources.

The vendors submitted revised designs which are summarized in Tables 5-7 through 5-9. A comparison of these designs shows that the CHX system recovers the maximum amount of energy from the flue gas (31 868 MJ/h at average winter condition). However, at similar fluid flow rates the heat transfer coefficient for the teflon-coated copper alloy tube used by CHX system is less than the heat transfer coefficient for the borosilicate glass tube exchanger designed by Flue Gas Resources and the stainless steel tubes heat exchanger specified by Air Froehlich AG.

At average operating conditions, the boiler efficiency would be raised by about 5.75% if CHX system is used to recover waste energy. The glass tube exchanger will raise the efficiency by 5.35% and the steel tube exchanger by about 3.95%.

The flue gas side pressure drop through the condensing heat exchanger is significantly higher for both the CHX system and the glass tube exchanger. Since the existing I.D. fan on Boiler #11 does not have requisite operating margin to overcome the combined effect of the heat exchanger pressure drop and the cooling of flue gases, it would be necessary to install an additional fan to maintain flue gas flow rate. It is estimated that a fan of design cold static pressure of about 254 mm W.C. might be sufficient depending upon the heat exchanger.

The design fan power would be about 175 kW if the fan is mounted upstream of the heat echanger. The design fan power would be about 100 kW if a fan of corrosion resistant material is installed downstream of the heat exchanger.

The cumulative power requirement for the plant including the additional power requirements for the fan would essentially remain the same.

On the waterside, the CHX system has the highest pressure drop of the three alternative systems. Nevertheless, the plant has excess capacity on its make-up water pumps to accomodate the increment in pressure drop.

A schematic of the general layout for installing a heat exchanger in the Boiler #11 flue gas path is shown in Figure 5-3. As shown in the figure, the flue gas path would be interrupted near the I.D. fan exit and a pneumatic damper would be installed to divert the flue gas to the condensing heat exchanger. There is no space available in the boiler plant; therefore the condensing heat exchanger would be installed immediately beyond the boiler plant walls.

A new I.D. fan would be installed in the flue gas path either upstream or downstream of the condensing heat exchanger depending upon the design selected.

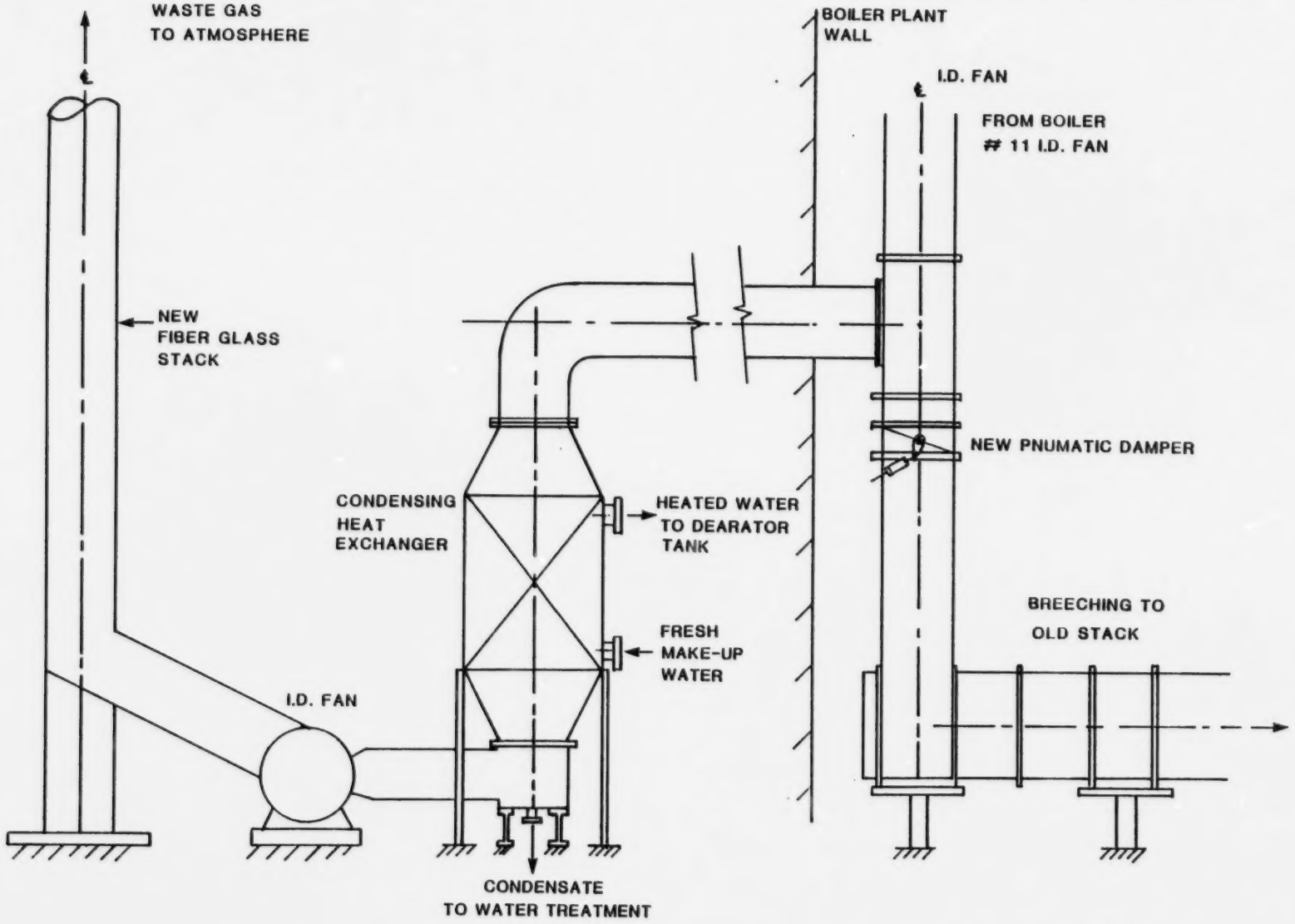

FIGURE 5.3 SCHEMATIC FOR INSTALLING A CONDENSING HEAT EXCHANGER ON BOILER No. 11 .

TABLE 5-7 PREDICTED PERFORMANCE FOR FLUE GAS CONDENSING HEAT EXCHANGERS FOR BOILER #11

(WINTER CONDITIONS)

VENDOR DESIGN PARAMETERS	CHX	FGR	AFR
FLUE GAS SIDE			
Flow Rate, kg/h	185 452	185 452	185 450
Inlet Temperature, °C	148.9	148.9	149.0
Outlet Temperature, °C	56.0	48.9	60.0
Pressure Drop, mm W.C.	153.42	124.71	20.39
BOILER FEED WATER SIDE			
Flow Rate, kg/h	147 420	147 420	147 600
Inlet Temperature, °C	18.9	18.9	19.0
Outlet Temperature, °C	70.9	63.1	48.0
Pressure Drop, kPa	105.91	36.75	16.0
ENERGY RECOVERED			
Sensible Heat, MJ/h	19 222.6	-	-
Latent Heat, MJ/h	12 645.4	-	-
Total Heat, MJ/h	31 868.0	27 274.8	20 697.4

Note: See Table 5-3 for vendor names.

TABLE 5-8 PREDICTED PERFORMANCE FOR FLUE GAS CONDENSING HEAT EXCHANGERS FOR BOILER #11

(SUMMER CONDITIONS)

VENDOR DESIGN PARAMETERS	CHX	FGR	AFR
FLUE GAS SIDE			
Flow Rate, kg/h	137 452	137 452	137 450
Inlet Temperature, °C	148.9	148.9	149.0
Outlet Temperature, °C	61.6	50.8	66.0
Pressure Drop, mm W.C.	89.15	70.87	12.24
BOILER FEED WATER SIDE			
Flow Rate, kg/h	90 720	90 720	90 850
Inlet Temperature, °C	40.6	32.2	32.0
Outlet Temperature, °C	85.0	77.6	64.5
Pressure Drop, kPa	41.51	14.55	6.0
ENERGY RECOVERED			
Sensible Heat, MJ/h	13 403.3	-	-
Latent Heat, MJ/h	3 470.8	-	-
Total Heat, MJ/h	16 874.1	17 205.2	12 359.2

Note: See Table 5-3 for vendor names.

TABLE 5-9 CONDENSING HEAT EXCHANGER SPECIFICATIONS FOR BOILER #11 AT DOMTAR FINE PAPERS MILL, CORNWALL

VENDOR	CHX	FGR	AFR
Tube Side Fluid	Water	Water	Water
Tube Material	Teflon Coated Copper Alloy 706	Borosilicate Glass KG-33	Stainless Steel AISI 304
Number Passes on Tube Side	-	-	2
Units	1	1	2
Total Heat Exchange Area, sq.m.	1997.51	1508.93	752.00
Height, cm	579.42	464.82	80.00
Depth, cm	618.74	335.28	574.00
Width, cm	274.32	304.80	160.00
Dry Weight, kg	29 243	12 739	5 000
Wet Weight, kg	41 514	19 783	7 300

Note: See Table 5-3 for vendor names.

The cooler waste gases would be exhausted through a fibreglass stack and the ducting between the heat exchanger exit and the stack would be lined with corrossion resistant material.

Air Froehlich has quoted the heat exchanger cost in Cost-Insurance-Freight (C.I.F.) Montreal basis while the cost of heat exchangers quoted by the Dibar Engineering and Sales, Inc. and Flue Gas Resources are Freight-On-Board (F.O.B.) from their respective fabrication shops. These costs were converted to C.I.F. Montreal basis and reported in Table 5-10.

To assess the merits of the three designs on an economic basis, the heat exchanger system costs might be calculated in terms of dollars per unit of saved energy. On this basis, the steel tube heat exchanger supplied by Air Froehlich has the lowest cost, i.e. Cdn $1.77 per Giga-Joule-Saved-per-Year. As reported in Table 5-10 the cost of the CHX system is the highest of all the designs.

The total capital cost of retrofitting Boiler #11 with a flue gas condensing heat exchanger is calculated on an order of magnitude basis. The calculations are shown in Appendix H. The contingencies included in the total capital cost are 15% for the CHX system and 25% for the glass tube and steel tube exchangers because the vendor of CHX system has submitted a quotation for necessary peripherals.

The total capital cost reported in Table 5-10 has an accuracy of ±30%.

The capital cost for the CHX system is the highest, while the steel tube heat exchanger supplied by Air Froehlich AG would cost the least. Nonetheless, the simple payback period would be the lowest for the glass tube heat exchanger supplied by Flue Gas

TABLE 5-10 COMPARISON OF CONDENSING HEAT EXCHANGERS DESIGNS FOR BOILER #11 AT DOMTAR FINE PAPERS MILL, CORNWALL

VENDOR	CHX	FGR	AFR
SAVINGS			
Heat Recovery Rate (avg.), MJ/h	24 371.05	22 240.00	15 138.17
Annual Fuel Savings, GJ	209 591.03	191 264.00	130 188.30
Change in Boiler Efficiency, %	5.75	5.35	3.95
Fuel Cost, $/GJ	4.05	4.05	4.05
Total Savings, $Cdn/y	848 844	774 619	527 263
COSTS			
Heat Exchanger (15% taxes) in Canadian Dollar	826 925	484 930	230 690
in $Cdn/(GJ-Saved-per-Year)	3.95	2.54	1.77
Total Capital Cost (± 30%)	2 012 869	1 632 096	1 218 956
Total Capital Cost in $/GJ-saved-per-year	9.60	8.53	9.36
Operating & Maintenance Cost in $/GJ-saved-per-year	0.30	0.25	0.28
Simple Payback, months	24 - 28	20 - 25	22 - 28

Notes:

1. See Table 5-3 for vendor names.
2. Total Capital Cost estimated on order of magnitude basis (see Appendix H).

Resources, U.S.A. The simple payback period would depend upon the actual usage of the heat exchanger and the cost of energy.

The maintenance any of these systems is likely to be of the same order of magnitude.

All the three condensing heat exchangers have been commercially applied. Both Flue Gas Resources and Condensing Heat Exchanger Corporation have provided a list of large scale installations in North America.

Among the three heat exchangers the steel tube heat exchanger is the most susceptible to corrosion and pitting. As mentioned in Section 2.0, the research on materials of construction of condensing heat exchangers has shown that stainless steel 304 is susceptible to pitting under prolonged exposure to condensing flue gases. This susceptibility would be greater if the flue gas is produced by combustion of fuel oils which usually have a greater sulphur content than natural gas.

Therefore, although the stainless steel tube heat exchanger designed by Air Froehlich AG costs the least of all the three designs, it is not the most suitable.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The extraction of low temperature thermal energy from waste gases requires heat exchange equipment constructed from corrosion resistant materials such as metal-plastic composites, fibre-reinforced polymers, ceramics, speciality steels, aluminium or copper alloys and high-strength glass.

Industrial application of flue gas condensing technology has been predominently European, since the cost of energy in Europe is usually higher than in North America. During the course of this study both European and North American designers and/or vendors of flue gas condensing heat recovery equipment were contacted. From the responses of the vendors it is apparent that the majority of designers and vendors of flue gas condensing heat recovery equipment supply only smaller size units for residential or industrial applications.

The results of this study show that flue gas condensing heat recovery systems may be applied on large scale industrial boilers if suitable low temperature heat utilization potential exists in the boiler environment.

Many of the commercially available stainless steel tube heat recovery systems are unsuitable for the low temperature application of condensing flue gases unless the colder part of the heat exchanger is constructed of stainless steel series 300 and 409 alloys. These materials were found to be corrosion resistant during tests conducted by the American Gas Association. The Stainless Steel 304 is resistant to corrosion but it suffers localized pitting under prolonged exposure.

The other main conclusions which may be drawn from this work are related specifically to the representative large scale

natural gas fired boiler selected for the project, i.e., the main power boiler (#11) at Domtar Fine Papers Mill, Cornwall, Ontario.

On the basis of the site-specific work carried out during the study it may be concluded that:

- The main power boiler (#11) at this plant is currently operated at 81 to 83% efficiency by recovering sensible heat from the boiler exhaust to heat combustion air. The flue gases leave the air heater at about 150°C and comprise about 14.55 volume percent water vapour. Hence, substantial amount of energy may be recovered by cooling the flue gases below the dew point.

- The sulphur content in the natural gas and consequently the combustion products is insignificant; therefore the cooling of flue gases below dew point would not lead to excessive corrosion in the flue gas handling equipment.

- Three vendors (the Condensing Heat Exchanger Corporation, U.S.A. through their Canadian representatives Dibar Engineering and Sales, Inc.; Flue Gas Resources, U.S.A.; and Air Froehlich AG Fuer Energierueckgewinnung of Switzerland) could design and supply flue gas condensing heat recovery equipment for large scale industrial boilers such as Boiler #11.

- The TEFLON-coated-copper-tube CHX system designed by Condensing Heat Exchanger Corporation could recover 24 371 Mega-Joule-per-hour at average conditions. This would raise the boiler efficiency by 4.75 percent.

- The borosilicate glass tube heat exchanger designed by Flue Gas Resources would deliver an annualized average saving of approximately 22 240 Mega-Joule-per-hour. This would raise boiler efficiency by about 5.35 percent.

- The AISI 304 stainless steel tubes heat exchanger supplied by Air Froehlich AG would recover approximately, 15 138 Mega-Joule-per-hour at average operating conditions. The boiler efficiency would increase by about 3.95 percent.

- All the three heat recovery systems would require an additional fan in the flue gas path to draw the gases through the heat exchanger and force them out of the stack.

- The path for cooler flue gas would have to be protected by corrosion resistent material/lining if a fuel other than the natural gas of given composition is to be fired with the condensing heat exchanger in operation.

- The total annual energy savings would range between $527 000 and $849 000 depending upon the selection of condensing heat exchanger, annual operating load, and average fuel cost.

- The cost of installing a flue gas condensing heat exchanger to extract energy from Boiler #11 flue gases ranges between 1.2 and 2.0 million Canadian Dollars.

- The stainless steel tube heat exchanger appears to be the most efficient of the three systems investigated. It costs about $1.77 for each Giga-Joule of energy saved per year. The glass tube heat exchanger ranks second with a cost of $2.54 for each Giga-Joule saved per annum. The corresponding value for the CHX system is $3.95.

- The payback period based on order of magnitude total capital cost ranges between 20 and 28 months.

RECOMMENDATIONS

Taking into consideration the above conclusions, it is recommended that Domtar Fine Papers Mill carry out the following modifications in their boiler plant:

- A flue gas condensing heat exchanger should be installed on the Boiler #11 to recover waste energy and improve boiler efficiency.

- The borosilicate glass tube heat exchanger designed by Flue Gas Resources should be given a higher priority when selecting a heat recovery system since it has the shortest pay-back period and the heat exchanger material is corrosion resistant.

- The ducting after the heat exchanger and equipment such as dampers or I.D. fan should have corrosion resistant lining. The material generally in use for lining the duct is FRP.

- A new fibreglass stack should be installed to release the cooler combustion products to the atmosphere.

NOMENCLATURE

NOMENCLATURE

Symbols

C_p	Specific heat, kJ/kg/h or /°C
Cdn	Canadian
SFr	Swiss Franc
T	Temperature, °C
W.C.	Water Column
HHV	Higher Heating Value
LHV	Lower Heating Value

Units

B.H.P.	Boiler Horse Power
Btu	British Thermal Unit
°C	Centigrade degree
d	Day
°F	Fahrenheit degree
g	Gramme
h	Hour
J	Joule
l	Litre
m	Meter
min	Minute
Pa	Pascal
y	Year
W	Watts

Prefixes

m	Milli, 10^{-3}
k	Kilo, 10^{3}
M	Mega, 10^{6}
G	Giga, 10^{9}
T	Tera, 10^{12}

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BIBLIOGRAPHY

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APPENDICES

APPENDIX A
SPECIFICATIONS FOR BOILER #11
AND ANCILLARY EQUIPMENT

TABLE A-1 SPECIFICATIONS FOR BOILER #11

Built by: Babcock-Wilcox & Goldie-McCulloch Ltd., Year 1959	
Type : Single Pass B & W Stirling Two Drum without Gas Baffles	
Design Capacity, kg Steam/h	175 000
Design Pressure, kPag.	4 998.9
Operating Pressure at Drum Outlet, kPag.	1 379.0
Registered Horse Power, BHP	2 066.5
Steam Drum Dimensions	1 829 mm I.D. x 11 278 mm
Mud Drum Dimensions	1 067 mm I.D. x 8 001 mm
Tube Diameter, boiler	63.5 mm swaged to 50.8 mm
Tube Diameter, furnace	76.2 mm swaged to 63.5 mm
Circumferential Heating Surface, (boiler), m^2	1 919.84
Projected Radiant Heating Surface (furnace), m^2	566.71
Number of Burners on Furnace	6
Heat Loss with Natural Gas at Design Conditions, % (Manufacturers Data)	16.7

APPENDIX A-2 BOILER FEED WATER PUMPS FOR BOILER #11

Installation	1959
Made by	Canadian Ingersoll Rand
Serial No.	52 458 - K, Size 4-GT
Static Head, m	237.4
Fluid Rate, lit/min	4 731.63
R.P.M.	3 500
Brake Horse Power	310
Turbine	Forthington
Serial No.	22 429, Type S-2R
Steam Pressure, kPag.	1 137.5
Temperature, °C	189.4
Exhaust Pressure, kPag.	103.4
R.P.M.	3 600

TABLE A-3 FORCED DRAUGHT FANS ON BOILER #11

Fan #1

Make	Canadian Sirocco
Size	542
Serial No.	102 A - D 50 Arrgt. 3 Airfoil Fan
Order No.	C 63497 - 1
Motor No.	2671, HP 150, R.P.M. 1176, V-550

Fan #2

Make	Canadian Sirocco
Size	542
Serial No.	-
Order No.	C 63497 - 22670, HP 150, R.P.M. 1176, V-550

Double Variable Inlet Control Vanes

Single Outlet Louvre Shut-Off Damper

Bearings — 61.9125 mm Dodge Water Cooled Sleeveoil Pillow Blocks

Shaft Couplings - Ajax No. 3½ S.

Performance of each fan

Duty	Rate kg/h	Rate cu.m./min.	Static mm	Temp. °C	Sp.Vol.	R.P.M.	B.H.P.
Test	106 140	1 579	359.41	40.6	0.893	1180	143
Net	92 305	1 310	276.35	26.5	0.854	1180	106

TABLE A-4 SPECIFICATIONS FOR COMBUSTION AIR HEATER ON BOILER #11

Type	Vertical Tubular
Made by	Babcock-Wilcox & Goldie-McCulloch
Installed	1959
Hot Fluid	Boiler #11 Exhaust Gas
Cold Fluid	Combustion Air
Air Temperature, °C	
Inlet (Design)	26.7
Outlet (Design)	271.1
Design Air Flow Rate, kg/h	147 000
Air Side Passes	4
Exhaust Gas Side Passes	1
Heating Surface, m^2	5 834.31
Tube O.D., mm	50.4

TABLE A-5 SPECIFICATIONS FOR INDUCED DRAUGHT FANS ON BOILER #11

Make	Canadian Sirocco
Size	565 DI 2/3 DW Series 90, Arrgt. 3
Order No.	C 63497 - 3
Motor No.	2704 - H.P.700, R.P.M. 889, V-550

Performance:

Duty	Rate kg/h	Sp. Vol. cu.m./kg	Rate cu.m/min	Static mm	Temp. °C	R.P.M.	B.H.P.
Test	239 039	1.249	4 978	461.72	182.2	885	681
Net	207 742	1.201	4 162	353.57	165.6	885	511

Note:

New Wheel and Shaft installed on November 11, 1962.

APPENDIX B

SAMPLING AND ANALYSES OF FLUE GAS COMPONENTS

APPENDIX B

SAMPLING AND ANALYSES OF FLUE GAS COMPONENTS

To establish the viability of retrofitting a flue gas condensing system to the main power boiler at Domtar Fine Papers Mill, Cornwall, Ontario, the exhaust gases from Boiler #11 were sampled, and analysed using the procedures described herein.

Two series of sampling measurements were made on the 16th of October, 1985. The first series of samples were collected between 09:20 and 10:35 hours, and the second series was collected from 10:55 hours to 11:30 hours.

The sampling train consisted of a dehydrator tube, and a series of four TEFLON-coated plastic bottles. The sampling train was cooled by keeping it submerged in an ice bath. All the bottles and their contents were dried and weighed prior to testing.

The collected gas samples were analysed according to standard procedures to determine the oxygen, carbon monoxide, carbon dioxide, sulphur dioxide and nitrous oxides concentrations in the flue gas.

Samples were collected at three points on the flue gas path:

1. Boiler Outlet
2. Air Heater Inlet
3. Air Heater Outlet

Moisture Content Measurement

The moisture content was determined by measuring the weight of the impinger bottle before and after the tests.

Sulphur Dioxide Measurement

The method for determining the sulphur dioxide content in a gas sample is in accordance with the Environment Canada Report number EPS-1-AP-74-3.

In this method, a gas sample is extracted at a fixed rate. A prescrubber of 80% isopropanol separates sulphuric acid mist (including sulphur trioxide) from sulphur dioxide. The sulphur dioxide is oxidized to sulphuric acid in a 3% hydrogen peroxide solution. The resulting solution is analysed for sulphate by the barium perchlorate-thorin indicator titration method.

The results obtained shown in Table B-1, were below the limit of detection of the method.

Measurement of Nitrogen Oxides

The method for determining the concentration of nitrogen oxides in a gas sample is in accordance with the Environment Canada Report number EPS-1-AP-77-3.

This method is called "the Phenol-Disulphonic Acids Colourimetric Procredure for the Determination of Total Oxides of Nitrogen in Gaseous Emissions from Combustion".

In this method the gas sample is admitted into a evacuated flask containing an oxidizing-absorbing solution of hydrogen peroxide in dilute sulphuric acid. The oxides of nitrogen are converted to nitric acid by gas phase oxidation due to oxygen in the sample and by reaction with the absorbing solution. The resulting nitrate ion is reacted with phenoldisulphonic acid to produce a yellow compound (the tri-ammonium salt of 6-nitro, 1-phenol-2- 4-disulphonic acid) whose concentration is measured colourimetrically.

TABLE B-1 MOISTURE AND SO_2 - ANALYSES FOR BOILER #11 FLUE GASES

SAMPLING POINT	TIME HOURS	SO_2 CONCENTRATION PPM *	MOISTURE (Vol %)
Boiler Outlet	09:20-09:50	0.3	14.4
	10:55-11:25	0.3	14.8
Air Heater Inlet	09:20-09:50	0.3	14.5
	10:55-11:25	0.3	14.5
Air Heater Outlet	09:20-09:50	0.3	14.5
	10:55-11:25	0.3	14.6

* Dry gas at 101.309 kPa and 25°C.

Calibration curves, prepared using samples of known nitrate content are used to determine the amount of nitrate in the test sample.

The results of the analyses are shown in Table B-2.

Measurement of Oxides of Carbon, and of Oxygen

Six "TEFLON" coated sample bags were filled with flue gases from Boiler #11. The oxygen and carbon dioxide concentrations were measured using an Orsat apparatus.

The carbon monoxide content was determined by using chromatographic methods.

The results of these analyses are presented in Table B-3.

TABLE B-2 NO_x - ANALYSES FOR BOILER #11 FLUE GASES

SAMPLING POINT	TIME HOURS	NO_x CONCENTRATION PPM *
Boiler Outlet	10:24	5.5
	11:36	4.6
Air Heater Inlet	10:24	5.2
	11:36	4.6
Air Heater Outlet	10:24	5.2
	11:36	4.5

* Dry gas at 101.309 kPa and 25°C.

TABLE B-3 CO, CO_2 AND O_2 - ANALYSES FOR BOILER #11 FLUE GASES

SAMPLING POINT	TIME HOURS	CO (PPM)	CO_2 (vol %)	O_2 (vol %)
Boiler Outlet	10:32	-	10.6	1.4
	10:35	15	10.4	1.6
	11:36	-	10.5	1.9
	11:38	10	10.4	1.6
Air Heater Inlet	10:25	30	10.4	2.0
	10:27	-	10.6	1.8
	11:38	-	10.2	1.6
	11:40	15	10.2	2.8
Air Heater Outlet	10:27	-	10.0	3.4
	10:29	15	9.6	3.4
	11:37	10	9.2	3.2
	11:39	-	9.6	3.5

APPENDIX C

OPERATING CONDITIONS FOR THE BOILER #11 AT

DOMTAR FINE PAPERS MILL, CORNWALL, ONTARIO

APPENDIX C

OPERATING CONDITIONS FOR THE BOILER #11 AT DOMTAR FINE PAPERS MILL, CORNWALL, ONTARIO

The data included in this Section have been extracted from records of the Boiler #11 operation during the twelve-month period from October, 1984 to September, 1985. Additional tests were carried out on October 16, 1985 to gather data on the flue gases discharged from boiler #11.

Boiler

Operating Pressure at Drum Outlet, kPag	1 379
Annual Operating Time, hours	8 600
Time on Average Load, %	80

Fuel

Type of Fuel	Natural Gas
Flow rate, litre/kg steam-min	71.79
Heating Value, MJ/cu.m.	38 953.6
Temperature, °C	40
Composition, vol%	
Nitrogen	1.779
Carbon Dioxide	0.362
Methane	95.775
Ethane	1.974
Propane	0.0109
Sulphur, milligrams/cu.m.	0.970

Boiler Feed Water

Temperature, C	111
Pressure, kPag	1 439
De-aerator Pressure Drop, kPag.	7
Make-Up Water Flow Rate, kg/h	
Summer Average	90 850
Winter Average	147 600
Make-Up Water Flow Rate, %	
Summer Average	70
Winter Average	81
Make-Up Water Temperature, °C	
Summer Average	32
Winter Average	19

Steam

Generation Rate, kg/h:	
Summer: Average	129 300
Maximum	167 000
Minimum	91 700
Winter: Average	181 400
Maximum	227 700
Minimum	138 600
Annual: Average	156 000
Temperature, °C	197
Pressure, kPag.	1 379
Quality	Saturated
Average Power Output, MW	120.87
Blow-down, % of Steam generated	5-6

Combustion Air Heater

Type	Shell & Tube
Air Flow Rate, kg/h	(see Appendix D)
Combustion Air Temperature, °C	
Inlet	
Winter	-15
Summer	25
Outlet	243-260
Air Pressure	Atmospheric

Flue Gas

Flow Rate, kg/h	(see Appendix D)
Stack Inlet Temperature, °C	144-149
Composition, vol % (WET)	
Nitrogen	74.361
Water Vapour	14.550
Carbon Dioxide	8.203
Oxygen	2.884
Hydrocarbons, ppm.	40-80
Carbon Monoxide, ppm.	10.680
Nitrogen Oxides, ppm.	4.144
Sulphur Oxides, ppm.	0.260

APPENDIX D

APPENDIX D

BOILER EFFICIENCY CALCULATIONS

The theoretical boiler efficiency was calculated using methods similar to the Steam Generating Units Power Test Codes developed by the American Society of Mechanical Engineers and the procedures developed in the Combustion Handbook for Canadian Fuels prepared by the Canadian Combustion Research Laboratory. The plant operations data and the flue gas analyses are presented in Appendices A, B and C, respectively.

D.1 Fuel Properties

Type of Fuel	Natural Gas
Ultimate Analysis, wt%	
Carbon	72.34
Hydrogen	23.96
Nitrogen	3.00
Oxygen	0.70
Sulphur, ppm	1.306
Heating Value, kJ/cu.m.	38 947.6
Density, kg/cu.m. @ NTP	0.7429

D.2 Combustion Calculations

The theoretical amount of air required for the combustion of the above given fuel is calculated assuming standard atmospheric conditions of 101.309 kPa and 25°C.

Weight of Fuel per unit Energy Content, kg/GJ

= 10^6 x Density (kg/cu.m.)/Heating Value (kJ/cu.m.)

= 10^6 x 0.7429 / 38 947.6

= 19.0745 kg/GJ

In calculating the stoichiometric amount of oxygen required to produce one Giga-Joule of energy from the fuel it is assumed that the fuel is dry. The moisture content of air has been neglected due to the fact that combustion air enters the boiler at about 245 Celsius degree and its contribution to the latent heat of flue gases would be negligible.

Fuel Component, kg/GJ		Oxygen, kg/GJ
C : 19.0745 x .7234 x 32 / 12.01	=	36.768
H : 19.0745 x .2396 x 16 / 2.016	=	36.269
Total Oxygen	=	73.037

D.2.1 Combustion Air

Fuel Oxygen: 19.0745 x .007	=	0.133 kg/GJ
Net Oxygen from Air	=	72.904 kg/GJ
Stoichiometric Dry Air Demand	=	314.920 kg/GJ

D.2.2 Stoichiometric Combustion Products

Carbon Dioxide : 19.0745 x 0.7234 x 44.01 / 12.01
: 50.568 kg/GJ

Nitrogen

Fuel : 19.0745 x 0.03
: 0.572 kg/GJ

Air : 314.92 - 72.904
: 242.016 kg/GJ

Total : 242.588 kg/GJ

Water : 19.0745 x .2396 x 18 / 2.016
: 40.839 kg/GJ

Stoichiometric Dry Flue Gas	=	293.156 kg/GJ
Stoichiometric Total Flue Gas	=	333.995 kg/GJ

D.2.3 Excess Air

The amount of excess air may be calculated by two methods: using the Combustion Charts available in "A Combustion Handbook for Canadian Fuels"; and using the flue gas analyses with the above stoichiometric flue gas calculations.

The CANMET Energy Research Laboratories have provided the charts based on the fuel analyses given by SNC. The heat loss calculations based on these charts are given later in this appendix.

The flue gas analyses for Boiler #11 are given in Appendices B and C.

The amount of carbon monoxide in the flue gas represents the amount of stoichiometric oxygen which remains unconverted during combustion. Therefore, to calculate the amount of net excess oxygen the oxygen content in the carbon monoxide has to be substracted from the free oxygen content in the flue gas.

Having obtained the net excess oxygen per kilogram of flue gas, it is essential to represent the oxygen content as a fraction of the amount of combustibles present in the flue gas. Knowing the amount of combustibles present in a Giga-Joule of fuel the percent oxygen in excess of the stoichiometric requirement can then be obtained.

Oxygen for Carbon Monoxide = CO (mol%) x 16 / 100/MW (flue gas)
= 10.681 x 10^{-6} x 16 / 27.991
= 6.1054 x 10^{-6} kg/kg flue gas

Free Oxygen in Flue Gas = O_2 (mol%) x 32 / 100/ MW (flue gas)
= 2.884 x 0.32 / 27.991
= 0.03297 kg/kg flue gas

Net Excess Oxygen in Flue Gas = 0.03297 - 6.1054 x 10^{-6}
= 32.964 x 10^{-3} kg/kg flue gas

Amount of Combustibles in Flue Gas

Carbon = 12.01 x (CO_2 (mol%) + CO (mol%)) / 100/ MW (flue gas)
= 12.01 x (8.2032 + 10.681 x 10^{-4}) / 2799.1
= 35.202 x 10^{-3} kg/kg flue gas

Hydrogen = 2.016 x H_2O (mol%) / 100 / MW (flue gas)
= 2.016 x 14.55 / 2799.1
= 10.479 x 10^{-3} kg/kg flue gas

Total = (35.202 + 10.479) x 10^{-3}
= 45.681 x 10^{-3} kg/kg flue gas

The net amount of oxygen per unit of combustibles is,

= 32.964 x 10^{-3} / 45.681 x 10^{-3}
= 0.7216 kg excess O_2/ kg combustibles

The amount of combustibles per Giga-Joule of fuel is calculated from ultimate analyses of the fuel given in D.1 above,

Weight of Combustibles per Giga-Joule of Fuel

= (kg fuel/GJ) x (Hydrogen (wt %) + Carbon (wt %)) / 100
= 19.745 x (0.23958 + 0.72346)
= 18.3695 kg combustibles/GJ

and,

Net Excess Oxygen per Giga-Joule of Fuel

= (kg combustibles/GJ) x (kg excess O_2/kg combustibles)
= 18.3695 x 0.7216
= 13.2554 kg excess O_2/GJ

Now, stoichiometric oxygen requirement was calculated in D.2.1 above to be,

= 72.904 kg O_2 from air/GJ

Therefore, the percent excess oxygen (or air) is,

= 100 x 13.2554 / 72.904
= 18.182% excess O_2 (or air)

The total amount of air supplied to the boiler is thus, 118.18 percent of the stoichiometric dry air calculated above, i.e.,

Combustion Air at Operating Conditions

= 314.92 x 1.18182
= 372.1788 kg Combustion Air/GJ

The total amount of flue gas at 18.18% excess air

= 372.1788 + 19.0745
= 391.2533 kg/GJ

The total amount of dry flue gas at 18.18% excess air

= 391.2533 - 40.8387
= 350.4146 kg/GJ

The amount of excess air may also be obtained by using the charts provided by CANMET Energy Research Laboratories for the natural gas of composition given in D.1. The determination of amount of excess air is shown in Figure D.1 Using the average compositions of Oxygen and carbon dioxide in the flue gas, the excess air may be determined on the abscissa. For the flue gas of composition given in Appendix C, the amount of excess air ranges between 17.2% and 20.2%, approximately. The average excess air percentage would be about 18.6%.

D.2.4 Heat Loss Calculations

The heat loss calculations are made using a procedure similar to ASME Power Test Codes.

Sensible Heat Loss

The specific heat of the flue gas may be assumed to be equal to the specific heat of air as nitrogen and oxygen comprise about 95% of the flue gas. Hence, the sensible heat for stoichiometric flue gas is calculated as,

Dry Heat Loss per Giga-Joule of Fuel (Summer Conditions)

= 293.1561 x 1.0046 x (149-25)
= 36 519.97 kJ/GJ
= 3.652 %

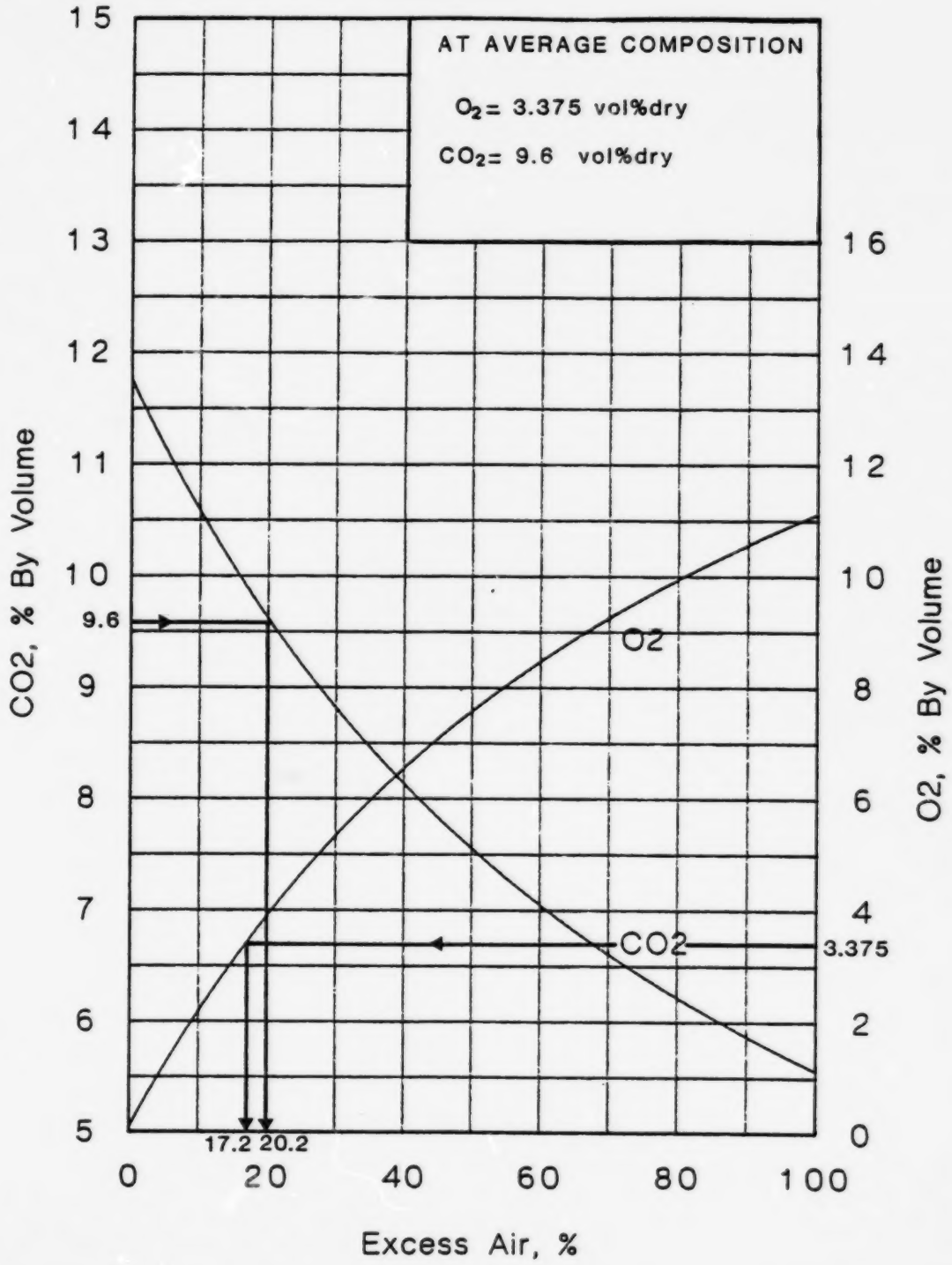

Figure D-1 CO2 and O2 Levels vs Excess Air
Fuel: Natural Gas (SNC Analysis)

The sensible heat loss due to the moisture in the flue gas is,

Sensible Heat Loss due to H_2O (Summer Conditions)

= kg Moisture in flue gas/GJ x C_p (kJ/kg °C) x (Temp. of flue gas - Temp. of Air)

= 40.8387 x 1.9255 x (149-25)
= 9751.00 kJ/GJ
= 0.975 %

Total Sensible Heat Loss (Summer Conditions)

= 36 519.97 + 9751.0
= 46 270.98 kJ/GJ
= 4.627 %

Similarly,

Dry Sensible Heat Loss per Giga-Joule of Fuel (Winter Conditions)

= 293.1561 x 1.0046 x (149- (-15))
= 48 300.61 kJ/GJ
= 4.83 %

and,

Sensible Heat Loss Due to H_2O (Winter Conditions)

= 40.8387 x 1.9255 x (149 - (-15))
= 12 896.49 kJ/GJ
= 1.29 %

Total Sensible Heat Loss (Winter Conditions)

= 48 300.61 + 12 896.49
= 61 197.10 kJ/GJ
= 6.12 %

Since, the boiler is operated with about 18.18 per cent dry excess air the sensible heat loss at the boiler operating conditions would be higher than the sensible heat loss at stoichiometric combustion.

The heat loss due to 18.18% excess air is calculated below:

Dry Sensible Heat Loss (Summer Conditions)

= 350.415 x 1.0046 x (149-25)
= 43 651.34 kJ/GJ
= 4.365 %

Dry Sensible Heat Loss (Winter Conditions)

= 350.415 x 1.0046 x (149 - (-15))
= 57 732.41 kJ/GJ
= 5.773 %

The loss in heat due to the combustion of hydrogen comprises: latent heat of vapourized moisture above the dew point temperature, and the sensible heat of liquid water below the dew point. This may be calculated by using the heat loss calculation formula given in CCRL's Combustion Handbook:

Total Heat Loss due to Combustion of Hydrogen

= (lb $H_2O/10^6$ Btu) x (1089 - Temp. of Air (°F) + 0.46 x Stack Temp. (°F))

Converting to SI Units yields,

= (kg H_2O/GJ) x 2.325552 x (1089 - Temp. of Air (°F) + 0.46 x Stack Temp. (°F))

For stoichiometric flue gas,

Heat Loss due to Combustion of Hydrogen at Summer Conditions

= 40.8387 x 2.325552 x (1089 - 77 + 0.46 x 300)
= 109.22 MJ/GJ
= 10.922%

Heat Loss due to Combustion of Hydrogen at Winter Conditions

= 40.8387 x 2.325552 x (1089 -5 + 0.46 x 300)
= 116.07 MJ/GJ
= 11.607 %

The heat loss due combustion of hydrogen does not change with the amount of excess air used for combustion, that is, the heat loss due to combustion of hydrogen is constant once the air supplied to the furnace equals or exceeds the stoichiometric requirement.

D.3 Boiler Efficiency

The total heat loss in the boiler is the sum of the dry flue gas sensible heat loss, the heat loss due to combustion of hydrogen, radiative heat loss, and heat loss due to the moisture in the combustion air.

TABLE D-1 TOTAL HEAT LOSS AND BOILER EFFICIENCY

EXCESS AIR, %	NIL		18.18	
OPERATING CONDITIONS	SUMMER	WINTER	SUMMER	WINTER
Temperature, °C				
Air	25	-15	25	-15
Flue Gas	149	149	149	149
Dry Flue Gas Loss, %	3.65	4.83	4.37	5.77
H_2 Combustion Loss, %	10.92	11.61	10.92	11.61
Radiation Loss, %	0.45*	0.45	0.45	0.45
Moisture in Air Loss, %	0.10*	0.10	0.10	0.10
Unaccountable Losses, %	1.50*	1.50	1.50	1.50
TOTAL	16.62	18.49	17.34	19.43
BOILER EFFICIENCY, %	83.38	81.51	82.66	80.57

* Manufacturers Data.

Table D-1 summarizes the results of heat loss calculations. The values of radiative heat loss, and heat loss due to moisture in air are taken from boiler manufacturers data. Unaccountable heat losses represent the inaccuracy in calculations and variations in boiler conditions.

The "Power Test Codes for Steam Generating Units" developed by the American Society of Mechanical Engineers recommend an abbreviated boiler efficiency test based on the gross heat losses from the boiler. The calculations for determining the efficiency by the abbreviated test are in essence, similar to those shown in Section D.2 above, hence the calculation procedure is not repeated here.

The boiler efficiency might also be estimated by using the charts provided by CANMET Energy Research Laboratories.

From Figure D.1, the amount of excess air was determined to be range between 17.2% and 20.2%.

Taking the average value of excess air to be 18.6%, the amount of dry combustion air, dry flue gas and total flue gas might be determined by using Figure D.2.

As shown in Figure D.2,

Dry Combustion Air, kg/kg fuel	19.61
Dry Flue Gas, kg/kg fuel	18.46
Total Flue Gas, kg/kg fuel	20.67

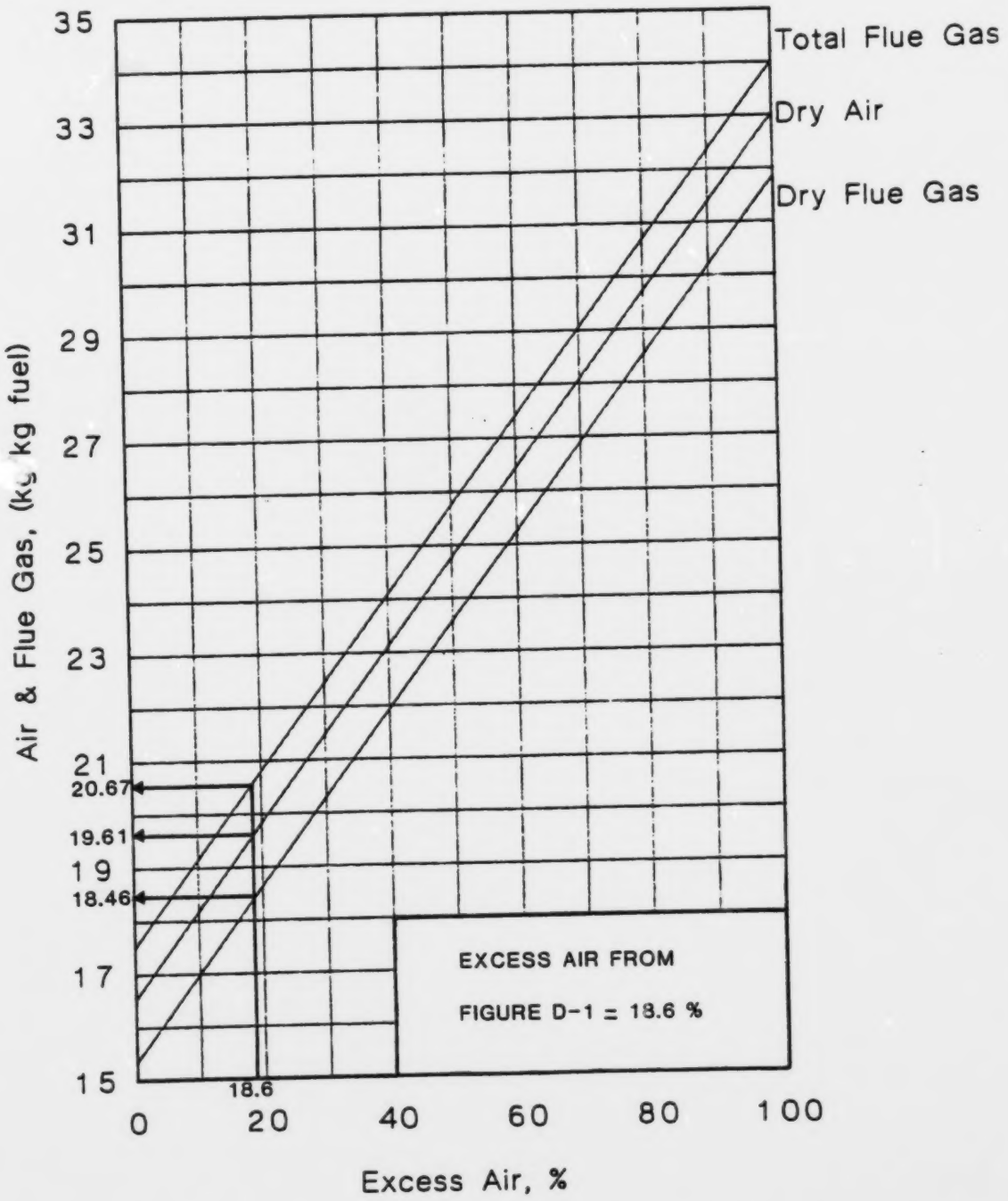

Figure D-2 Combustion Data, Weight Basis
Fuel: Natural Gas (SNC Analysis)

Converting the above values to Giga-Joule of fuel basis yields,

Dry Combustion Air, kg/GJ	=	19.61 x 19.0745
	=	374.051
Dry Flue Gas, kg/GJ	=	18.46 x 19.0745
	=	352.115
Total Flue Gas, kg/GJ	=	20.67 x 19.0745
	=	394.270

At summer average temperature of 25°C, the dry flue gas sensible heat loss is estimated using Figure D.3, to be 4.33 %. At winter average condition of -15°C, the dry flue gas sensible heat loss is estimated to be 5.95%.

Similarly, heat loss due to combustion of hydrogen may be estimated by using Figure D.4:

Heat Loss due to Combustion of Hydrogen (Summer)	10.1 %
Heat Loss due to Combustion of Hydrogen (Winter)	10.4 %

The total heat loss may then be calculated by assuming the values for radiative heat loss and heat loss due to moisture in air to be the same as those given in Table D-1. The results are summarized in Table D-2. From the results given in Tables D-1 and D-2, it may be concluded that the boiler efficiency ranges between 80.5% and 83.0% depending on the operating conditions.

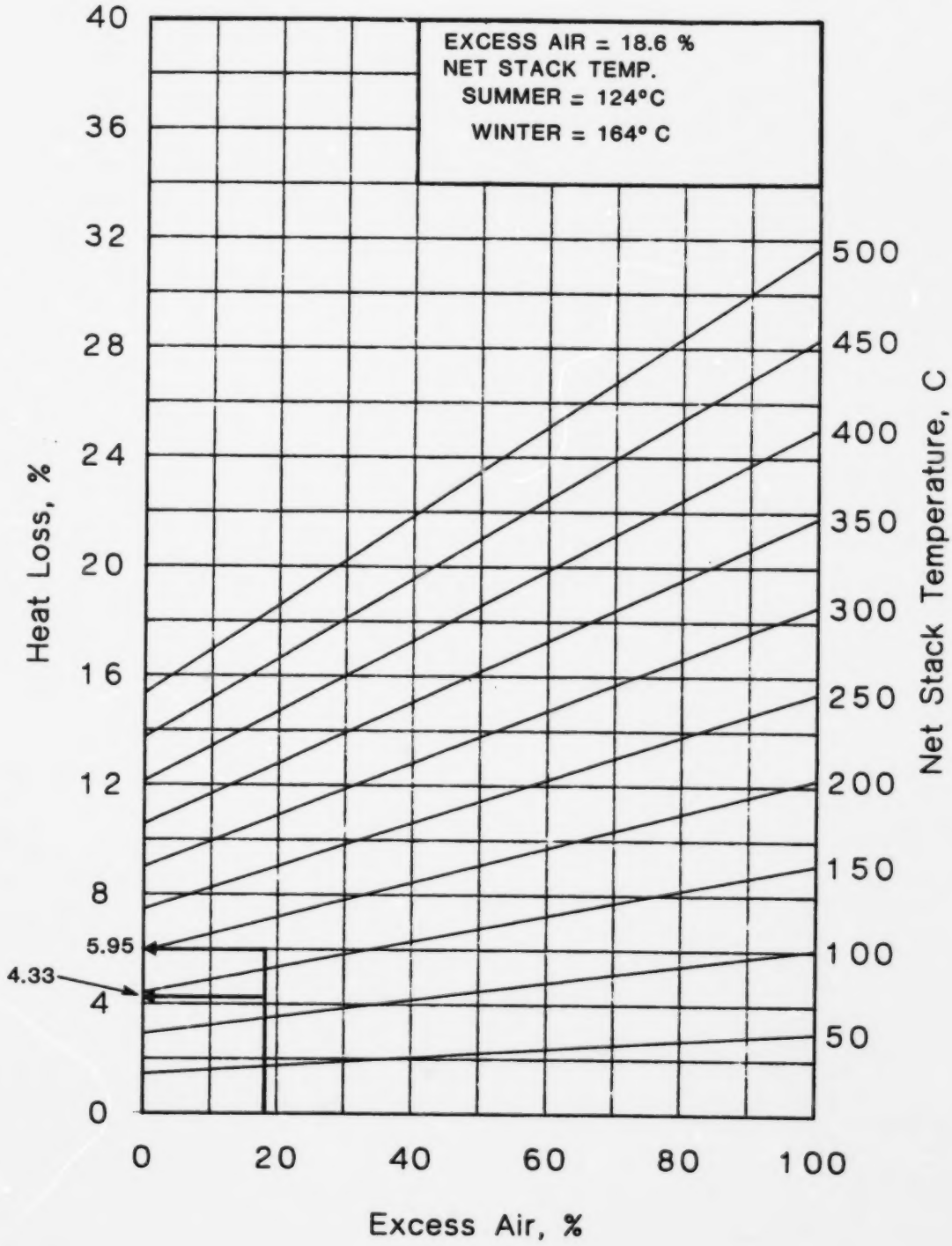

Figure D-3 Dry Flue Gas Loss
Fuel: Natural Gas (SNC Analysis)

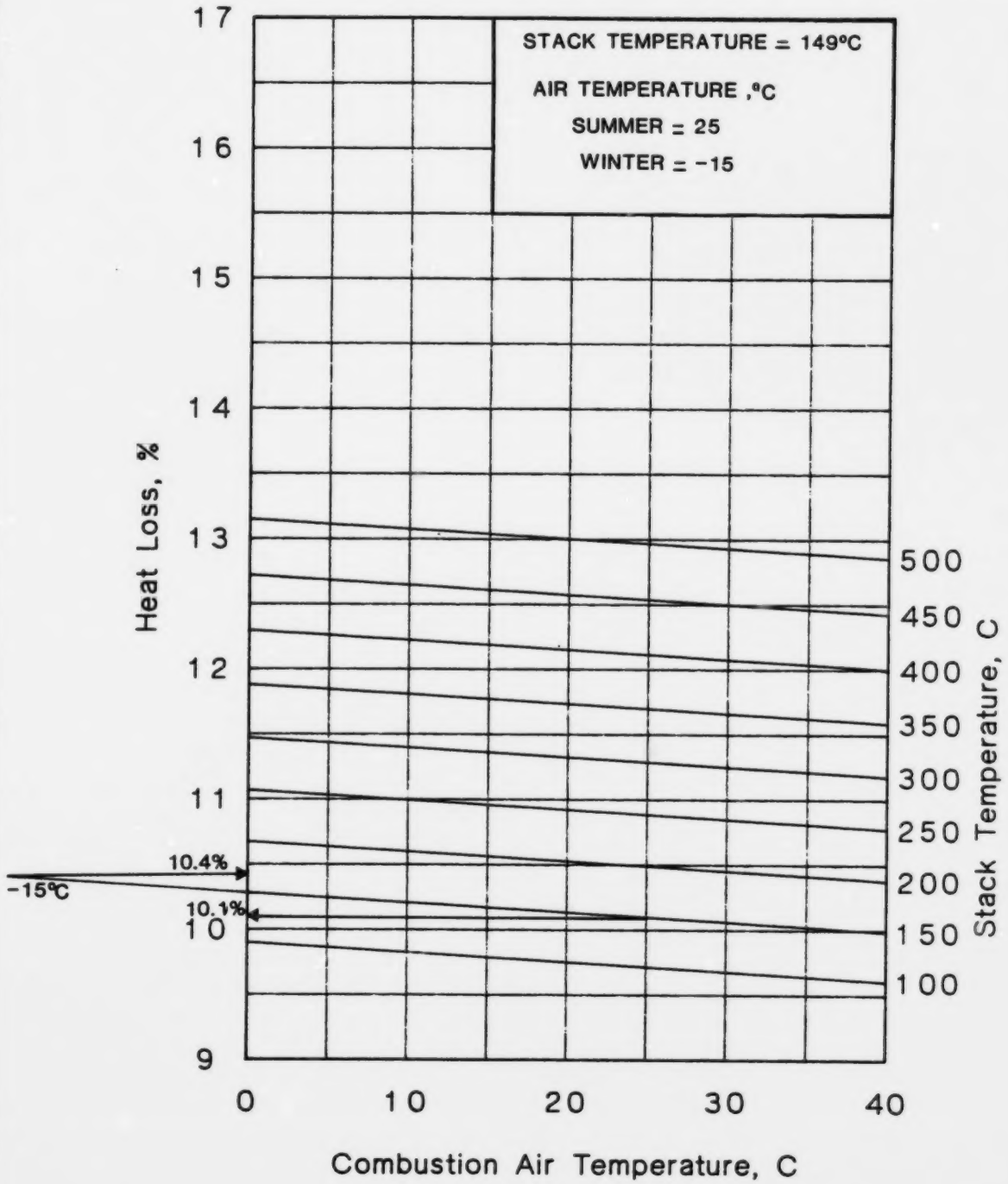

Figure D-4 Hydrogen Loss
Fuel: Natural Gas (SNC Analysis)

TABLE D-2 BOILER EFFICIENCY USING COMBUSTION CHARTS

HEAT LOSS, %	SUMMER	WINTER
Dry Sensible Heat Loss	4.33	5.95
Loss due to H_2 Combustion	10.10	10.40
Radiative Heat Loss	0.45	0.45
Loss due to H_2O in Air	0.10	0.10
Unaccountable Losses	1.50	1.50
TOTAL	16.48	18.40
BOILER EFFICIENCY, %	83.52	81.60

APPENDIX E

REQUEST-FOR-QUOTATIONS FOR A FLUE GAS

CONDENSING HEAT RECOVERY SYSTEM FOR BOILER #11

APPENDIX E

REQUEST-FOR-QUOTATIONS FOR A FLUE GAS CONDENSING HEAT RECOVERY SYSTEM FOR BOILER #11

DATA

Boiler

Operating Pressure at Drum Outlet, kPag		1 379
Steam Quality		Saturated
Steam Generation Rate, kg/h:		
Summer:	Average	129 300
	Maximum	167 000
	Minimum	91 700
Winter:	Average	181 400
	Maximum	227 700
	Minimum	138 600
Annual:	Average	156 000
Annual Operating Time, hours		8 600
Time on Average Load, %		80

Fuel

Type of Fuel	Natural Gas
Flow rate, litre/kg steam-min	71.79
Heating Value, MJ/cu.m.	38 953.6
Temperature, °C	40
Composition, vol%	
Nitrogen	1.779
Carbon Dioxide	0.362
Methane	95.775
Ethane	1.974
Propane	0.0109
Sulphur, milligrams/cu.m.	0.970

Flue Gas

Stack Inlet Temperature, °C	144 - 149
Flow rate (Winter Average) :	2000 cu.m./min
Composition, vol % (WET)	
Nitrogen	74.361
Water Vapour	14.550
Carbon Dioxide	8.203
Oxygen	2.884
Hydrocarbons, ppm.	40 - 80
Carbon Monoxide, ppm.	10.680
Nitrogen Oxides, ppm.	4.144
Sulphur Oxides, ppm.	< 0.260

Stack

Material	Brick lined Cement Column
Bottom Diameter (O.D.), cm	605.8
Bottom Thickness, cm	33
Height, m	76.2

I.D. Fan

Type: Canadian Sirocco 565 DI 2/3 DW Series 90	
Fan Rating (test), cu.m/min @ 182°C	4978
Fan Rating (net), cu.m/min @ 166°C	4162
Static Head, mm W.C.	18.18 (test), 13.92 (net)
BHP	661 (test), 511 (net)

DESIGN CRITERIA

Design a flue gas condensing heat recovery system for the maximum flue gas flow rate.

Hot Fluid	Flue Gas at conditions given above
Flow Rate	to be calculated
Cold Fluid	Process Water
Flow Rate, cu.m/min	11.5 - 19
Inlet Temperature, °C	26
Outlet Temperature, °C	Maximize
Pressure Drop	Specify
Material of Construction	Corrosion Resistant Metal, Glass, other

If more energy is available additional process water may be considered for alternate design.

Specify complete systems for recovery of waste energy by flue gas condensation (that is, heat exchanger, pumps, fans, and instrumentation).

Applicable equipment fabrication and testing codes must be indicated for each item.

Provide a listing of installed equipment of similar capacity/application designed or fabricated by your company.

Provide a breakdown of cost for each component of the system supplied by you.

Indicate energy savings based on the seasonal boiler usage given above.

TABLE E-1 REVISION TO REQUEST-FOR-QUOTATIONS
FOR A FLUE GAS CONDENSING HEAT
RECOVERY SYSTEM FOR BOILER # 11

(Revision #1)

DATA	
Same as in request-for-quotations	
DESIGN CRITERIA	
Hot Fluid	Flue Gas at previous conditions
Cold Fluid	Process Water
Flow Rate, cu.m/min	1.89
Inlet Temperature, °C	26
Outlet Temperature, °C	Maximize
Pressure Drop	Specify

Note: Other conditions remain the same as stated in the request-for-quotations.

TABLE E-2 REVISION TO REQUEST-FOR-QUOTATIONS
FOR A FLUE GAS CONDENSING HEAT
RECOVERY SYSTEM FOR BOILER # 11

(Revision #2)

DATA		
Boiler Feed Water		
Temperature, °C		111
Pressure, kPag		1 861.7
De-aerator Pressure Drop, kPag		7
DESIGN CRITERIA		
Hot Fluid	Flue Gas at previous conditions	
Cold Fluid	Boiler Feed Water Make-up	
Flow Rate, kg/h		
Summer Average		90 850
Winter Average		147 600
Temperature, °C		
Summer Average		32
Winter Average		19

Note: Other conditions remain the same as stated in the request-for-quotations.

APPENDIX F

DESIGN SPECIFICATIONS OF SELECTED FLUE GAS CONDENSING HEAT RECOVERY SYSTEMS

AIR FROEHLICH AG

fuer ENERGIERUECKGEWINNUNG

SWITZERLAND

snc

SPECIFICATION

Max. operating pressure	4 bar
Tested pressure	6 bar
Max. operating temperature:	
- flue gas side	250°C
- water side	95°C

CONDENSING HEAT EXCHANGER CORPORATION

U.S.A.

DESIGN SPECIFICATION
(50-50)

TUBE MATERIAL.....	COPPER ALLOY 706
TUBE SPECIFICATION.....	ASTM B-111
TUBE SIZE (O.D.).....	1.125 IN.
TUBE WALL THICKNESS.....	0.035 IN.
DESIGN PRESSURE.....	100 PSIG @ 200°F WATER
TEST PRESSURE.....	200 PSIG @ 100°F
DESIGN TEMPERATURE.....	250°F (WATER SIDE)
.....	500°F (GAS SIDE)
SHELL CASING MATERIAL.....	10 GA. CARBON STEEL
TEFLON COVERING.....	0.015 IN. (ON TUBE O.D.)
.....	0.060 IN. (ON GAS SIDE OF SHELL)
FLOW DIAGRAM.....	DRAWING NUMBER 81004-F

GAS FLOW RANGE	4000 - 1 000 000 lb/h
AIR FLOW RANGE	1600 - 500 000 c.f.m.
LIQUID FLOW RANGE	5 - 1200 U.S. g.p.m.

CONDENSING HEAT EXCHANGER CORP.

PARTS LISTING

Applicable Models: ALL DW SYSTEMS

Reference: DWG. No. 81004-F (Rev. 2)

Item No.	Description
1	**MODULATING FLUE GAS FLOW CONTROLLER** -Controls exhaust gas flow to the CHX by modulating a damper ahead of the CHX supply fan. Differential temperature sensing provides a dynamic response to changes in energy available for recovery. -Panel mounted and wired with differential temperature indication. -FIELD WORK- Install thermocouples (shipped loose) in ducts (2) - T/C extension wiring from T/C's to panel
2	**GAS FLOW CONTROL DAMPER MODULATING POSITIONER** -Opposed blade damper is available from CHX. -Standard positioners are electronic; receive signal from Item 1 above. -FIELD WORK- Mount positioner and connect linkage to damper - Control wiring from positioner to panel
5	**CHX SUPPLY FAN** -High temperature construction with shaft seal, heat slinger, and high temperature bearings. -Pulls exhaust gas from existing stack for energy recovery in the CHX - NO damper required in existing stack. -FIELD WORK- Depending on the specific job, fan may be skid mounted on heat exchanger base with discharge duct connected to CHX inlet or shipped separately with or without discharge duct - Three phase wiring from motor to starter
6	**HIGH FLUE GAS INLET TEMPERATURE CUTOUT** -Protects Teflon® from exhaust gas temperatures in excess of 500°F by shutting system down (CHX fan off and damper shut). -Panel mounted and wired with temperature indication. -FIELD WORK- Install thermocouple (shipped loose) in inlet duct - T/C extension wiring from T/C to panel
7	**HEAT EXCHANGER DIFFERENTIAL PRESSURE INDICATOR/CUTOUT** -Panel mounted and wired with indication. -FIELD WORK- Install sensing line (3/8" min.) to inlet plenum connection
8	**HIGH FLUE GAS EXIT TEMPERATURE CUTOUT** -Protects FRP outlet plenum and stack from exhaust gas temperatures in excess of 350°F by shutting system down. -Panel mounted and wired with temperature indication. -FIELD WORK- Install thermocouple (shipped loose) in stack - T/C extension wiring from the T/C to panel
9	**AUTO WASH SYSTEM** -A microprocessor based timing system cycles a control valve to intermittently wash down the shell side of the heat exchanger. Typical frequency is 2 minutes every 8 hours, which ensures peak operating efficiency. -FIELD WORK- Depending on the specific job, a short section of piping may be shipped loose and will require connection
10	**FIBERGLASS REINFORCED PLASTIC (FRP) EXHAUST PLENUM** -Includes a condensate drain trap and clear observation section for visual observation of condensate flow from condensation of water vapor in the exhaust gas (latent heat recovery). -FIELD WORK- Depending on overall height and transportation restrictions, the outlet plenum may be shipped separately which will require reassembly at the job site along with some miscellaneous support steel - Install condensate trap
12	**CARBON STEEL INLET PLENUM**
13	**HEAT EXCHANGER WITH WATER MANIFOLDS** -Entire gas (shell) side of heat exchanger is 100% Teflon® covered for superior long-term performance. -FIELD WORK- If heat exhanger is shipped with outlet plenum off, the bottom (inlet) water manifold will be shipped loose for connection to the heat excnanger at the job site.
14	**HIGH/LOW WATER FLOW CUTOUT** -Shuts down system on a loss of water flow or if water flow exceeds the unit design. -Panel mounted and wired with differential pressure indication. -FIELD WORK- Install pressure sensing lines (1/4" min.) from instrument to connections on water inlet and outlet manifolds. Isolation valves are provided on the manifold connections.

Item No.		Description
15		**RELIEF VALVE** -Provides redundant protection (ASME certified) against over pressure conditions. -FIELD WORK- Normally relief valve is installed on water outlet manifold. - Discharge piping must be provided and installed.
16		**WATER OUTLET HIGH TEMPERTURE CUTOUT** -Limits water outlet temperature from heat exchanger by shutting system down if temperature exceeds setpoint. -Panel mounted and wired with temperature indication. -FIELD WORK- Install thermocouple (shipped loose) in water outlet manifold connection - T/C extension wiring from T/C to panel
17		**WATER METER** -Provides indication of water flow for monitoring system performance. -FIELD WORK- Install meter in water supply piping

ITEMS IN THIS SECTION ARE NOT STANDARD EQUIPMENT ON EVERY INSTALLATION, BUT ARE INCLUDED WHERE NECESSARY FOR EACH SPECIFIC JOB.(Items included in quotations will be indicated by a check mark on the line provided next to each number.)

3	___	**FLUE GAS TEMPERING DAMPER MODULATING POSITIONER** -Tempering damper is available from CHX. -Standard positioners are electronic; receive signal from Item 4 below. -FIELD WORK- Mount positioner and connect linkage to damper - Control wiring from positioner to panel
4	___	**FLUE GAS INLET TEMPERATURE CONTROLLER** -Allows tempering of exhaust gas with ambient air to control inlet temperature to CHX at or below 500°F (modulating control). -Allows operation of CHX System when available exhaust gas temperature exceeds 500°F either occasionally or continuously. -Panel mounted and wired. -FIELD WORK- Install thermocouple (shipped loose) in inlet duct - T/C extension wiring from T/C to panel
11	✓	**WATER OUTLET TEMPERATURE CONTROLLER** -Allows modulating control of hot water outlet temperature at or below the set point. -Prevents system shutdown by the high water outlet temperature cutout in cases of reduced water flow by automatically over-riding the gas flow controller and limiting the amount of heat recovery by the system to what is actually required. -Panel mounted and wired. -FIELD WORK- Install thermocouple (shipped loose) in water outlet manifold connection - T/C extension wiring from T/C to panel
18	✓	**BTU COMPUTER** -Recommended on every installation. -Provides display of total energy recovered on a continuous basis along with remote display of total amount of water heated. -Panel mounted and wired. -FIELD WORK- Install temperature sensing elements (shipped loose) in water inlet and outlet manifold connections - Extension wiring from temperature elements to control panel - Extension wiring from water meter pulser head to control panel
19	___	**WATER PRESSURE BOOSTER PUMP** -May be required for process water heating applications. -Normally provided and installed by customer.
20	✓	**FLUE GAS OUTLET TEMPERATURE CONTROLLER** -Allows modulating control of exhaust gas flow on flue gas outlet temperature by over-riding the gas flow control system to protect the down stream duct work against high exhaust gas temperatures. -Panel mounted and wired. -FIELD WORK- Install thermocouple (shipped loose) in stack - T/C extension wiring from T/C to panel
	✓	**SIGNAL SELECTOR RELAY** -Required and included if flue gas outlet temperature controller and/or water outlet temperature controller option is included. -Panel mounted and wired. -FIELD WORK- NONE
	___	**ELAPSED TIME METER** -Provides display of total operating hours for system. -Panel mounted and wired. -FIELD WORK- NONE
*	___	**REMOTE TEMPERATURE INDICATING SYSTEM** -Allows remote monitoring of additional temperatures not included with the standard system. These points are: -Water inlet temperature -Boiler (or exhaust gas source) flue gas temerature -Existing stack temperature -Any other points desired -FIELD WORK- Install thermocouples (shipped loose) at desired locations - T/C extension wiring from T/C's to panel

(Item specification subject to change without notice)
Bulletin 1183-SW-7

FLUE GAS RESOURCES INCORPORATED

U.S.A.

SNC

Flue Gas Resources, Inc.

TECHNICAL SPECIFICATIONS for
GLASS TUBULAR HEAT EXCHANGERS

General Specifications

Recommended Temperature Service	425'F Continuous Duty 500'F Peak Excursion
Recommended Pressure Service Air Heater	10" WC Differential 20" WC Total
Water Heater	75 PSIG Liquid Side 20" WC Gas Side 125 PSIG Hydro Pressure Test

Equipment Specifications

Glass Tubes

Kimble KG-33 Borosilicate Glass Tubes manufactured by Owens-Illinois corporation. Borosilicate Glass Tubes comprise 100% of the heat transfer surfaces.

Tube Diameter	1" to 2" OD
Tube Wall Thickness	1.2mm to 2.0 mm AW
Maximum Temperature	955'F (strain point)
Nominal Burst Pressure	500 PSIG
Thermal Shock Resistance	365'F maximum T
Expansion Coefficient	1.78*10E-7 ft/ft/'F

Tube/Tubesheet Seals

Proprietary design flexible Viton grommets designed to allow for thermal expansion and vibration isolation of glass tubes. Glass tubes are removable and replacable. Excellent compression/memory characteristics of this seal insure long service life without cross-contamination.

Maximum Temperature	450'F Continuous Duty 525'F Peak Excursion
Sulfuric Acid Resistance	Excellent

Tubesheets

Proprietary synthetic glass fiber reinfored plate (.375-.500 in.) with cast resin surface.

Maximum Temperature	425'F Continuous Duty 500'F Peak Excursion
Sulfuric Acid Resistance	Excellent

Side Panels and Interitor Casing

Proprietary synthetic glass fiber reinforced plate (.250-.375 in.) with exterior high density fiberglass insulation covered with fiberglass skin for protection. Casing side panels are removable for inspection and maintenance.

Maximum Temperature	425' F Continuous Duty 500' F Peak Excursion
Sulfuric Acid Resistance	Excellent

Exterior Structural Framework

The entire unit is supported structurally by an exterior exoskeleton constructed of carbon steel framing members. The steel exoskeleton never contacts the flue gas. The steel exoskeleton is visible from the exterior of the unit for inspection.

Airturn (Airheater only)

Carbon steel plate construction stiffened as required, ready for field insulation.

Water Box Turns (Waterheater only)

Stainless steel plate construction of rectangular design with ANSI flanges and venting and relief ports. Header cover door is hinged to allow ease of inspection and maintenance. Header casing and door are built to ASME pressure vessel code specifications for the design pressure. Exterior surfaces of box headers are insulated with high density fiber glass insulation and covered with protective steel skin. Exterior surfaces are sandblasted and finish painted with high temperature epoxy paint.

Wash System (Required for systems fired with coal or with oil at least 20% of the time)

High volume, low pressure multiple nozzle system located above glass tube bank. Header pipes are high temperature plastic construction with 316 S.S. nozzles. Headers are mounted on the exterior of the heat exchanger casing with nozzles penetrating the casing through a Viton grommet. Nozzles and header sections are individually removable for service.

APPENDIX G

VENDORS' WARRANTIES AND LISTING OF PARTS

AIR FROEHLICH AG

fuer ENERGIERUECKGEWINNUNG

SWITZERLAND

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AIR FRÖHLICH AG für Energierückgewinnung
Romanshorner Strasse 100 CH-9320 Arbon/Switzerland
Telefon 071/46 55 25 Telex 71 400 Telefax 071/46 69 59

Dok. Nr. 22/9.85

General delivery and guarantee conditions

Translation of legally binding German edition

Scope of application

1 Unless other arrangements are expressly and in writing agreed upon in the confirmation of order, the following conditions shall be deemed to govern the relations between the parties.
Assembly, operating and maintenance instructions shall, where so mentioned in the confirmation of order, form an integral part of these conditions.
The customer shall draw the attention of AIR FRÖHLICH to legal, official and other regulations that have to be observed in the performance of the contract.

Scope of delivery

2 The scope and implementation of delivery shall be bindingly governed solely by our confirmation of order. Subsequent amendments which may prove necessary as the result of the customer having provided incorrect or incomplete information, shall be separately invoiced.

3 We reserve the right to depart from the construction specifications and those conditional upon manufacturing requirements as stipulated in our confirmation of order insofar as such changes do not affect the performance and dimensions of the finished product.
Diagrams and other documentation shall remain the property of AIR FRÖHLICH.

Delivery dates

4 Agreed delivery dates shall be calculated from the day on which the order is confirmed in writing and/or from the date of receipt by us of any necessary official permits. Loading day shall be deemed delivery day.

5 The delivery period shall be appropriately extended in the case of unforeseen events such as acts of God, etc. The period shall likewise be extended should the customer fail to produce the necessary documentation, should the order be amended or if the agreed payments are not made on time.

6 Should the delivery date not be met for reasons for which we are responsible, our liability for damages in the case of proven prejudice shall be limited to a maximum of 5% of the free ex-works sales price of that item which we are late in delivering.

7 We shall be entitled to make part deliveries.

Transport and transport insurance

8 The goods shall be carried, at our cost and risk, as far as the customer's building site or domicile.

9 The customer shall be responsible for off-loading in accordance with the technical instructions provided by AIR FRÖHLICH. The customer shall, on the delivery date indicated by ourselves, make available all necessary labour and equipment for the off-loading. The customer shall meet the cost of any delay or waiting time that the carrier may charge for as well as any additional expenses incurred if, through no fault of ours, the goods cannot be off-loaded at the appointed time.

10 Fragile goods (such as glass heat-echangers) shall be additionally insured against the ususal transport risks. The insurance shall be valid from place of departure to place of arrival (appliance mounting). It shall, however, in all cases end no later than 10 days after arrival of the goods with the recipient party. With respect to procedure to be followed in the case of damage, please see Arts. 13 and 14.

11 Should the goods be temporarily stored during the course of transport, the insurance cover shall also be valid for the continued transport to the final destination provided that such further transport be effected within 30 days of the goods having left our works. Should such temporary intermediate storage last longer, the customer may, before transport begins, request an extension of insurance cover.

12 Our insurance and liability exclude all direct secondary risks such as idle time, delayed deliveries, disruption, loss of value after repair, etc. The customer shall be responsible for having any such risks covered.

13 Damage reports shall be submitted to the carrier (rail or road) immediately or shall be noted on the delivery docket and signed. Damage which is not immediately apparent shall be reported no later than seven days after delivery failing which it will be assumed that the goods were delivered in perfect condition.

14 In the case of damage (other than trifling cases), we are to be immediately asked for the address of the responsible damage assessor who shall be called in to assess the damage.

Testing and assembly

15 The products shall be tested prior to dispatch and pursuant to our testing conditions.

16 During assembly, our assembly instructions and the indications of any staff that we may make available for the purpose shall be strictly observed. The cost of any such staff that we may provide shall be met by the customer.

Conditions of payment

17 Unless otherwise agreed, our prices shall be taken as net and in Swiss francs and shall fall due as follows:

- ⅓ of the invoiced total with order (confirmation of order)
- ⅓ of the invoiced total when the goods are ready for dispatch
- ⅓ of the invoiced total 30 days net after delivery

In the case of part deliveries, the appropriate part payments shall fall due. Payments in arrears shall be subject to interest on arrears notwithstanding any other rights we may have with respect to such delays. If, as the result of events beyond our control, the dispatch of completed goods or the assembly for commissioning thereof should suffer delay, payment shall be due as if the delivery, assembly and commissioning had taken place as envisaged. Payments shall likewise be due at the appointed dates even if additional work is required under the terms of our guarantee. The customer hereby relinquishes any right to offset against payments due any claims it may have on the supplier.

18 We shall be entitled to withhold consignments should we have any reason to doubt payment of the agreed sums. We shall not calculate interest on any payments already made to us.

Guarantee and liability

19 We hereby guarantee, the performance and quality of our products for a period of 12 months from delivery to the customer.

20 The guarantee shall not cover damage caused by an act of God, by the utilization of the delivered apparatus for a purpose other than that for which it was envisaged as stated in the confirmation of order or in a manner other than that indicated in the operating instructions, by excessive temperatures, temperature differences or speeds of temperature change or air or pressure conditions or by any failure to observe our instructions regarding the planning, on-site delivery and assembly of the plant.
The operational guarantee shall also lapse in the case of insufficient maintenance or cleaning or the use of unsuitable fuels. The guarantee shall not cover parts or fuels subject to normal wear and tear (such as piston rings, electrical components, fire-brick linings or V-belts).

21 The guarantee shall lapse if the customer fails immediately to register its claim in writing on discovering a fault. For claims concerning the performance guarantee, only measurements made in accordance with the recognised rules of the technique will be accepted. The guarantee shall also lapse if the customer effects or causes to be effected any alteration or repair work without our written approval.

22 We shall be deemed to have met our guarantee obligations if, at our discretion, we repair or replace any parts which can be shown to be imperfect or unusable as the result of faulty materials or workmanship. We shall meet the cost of any repairs or exchanges effected in our workshops.
The customer shall meet the cost of stripping and reassembling the device and of any transport involved.
Should the device be repaired on the spot, we shall meet all such costs as would have been incurred had the repair been effected in our workshops. In such cases, the customer shall, at its own expense, provide all conditions necessary for the execution of such work and especially any necessary auxiliary staff. Subject to special arrangements to the contrary, the customer shall be liable for the travel expenses of our mechanics.

23 Should our deliveries include apparatus from other manufacturers (such as burners, control units or ventilators), such apparatus shall be covered by the guarantee and delivery conditions of the respective manufacturers. We shall cede all claims under such guarantees to our customer and shall thus be absolved from any further liability on respect thereof.

24 We hereby expressly reject any further claims by the customer such as claims for reduction in the purchase price, damages in respect of secondary loss or redhibition.

25 Any execution of guarantee performance through AIR FRÖHLICH does neither interrupt nor restart the duration of guarantee.

Final provisions

26 Place of performance for both parties shall be the place of domicile of the seller.

27 Jurisdiction shall lie with the courts of Arbon.

28 The contract shall be subject exclusively to Swiss law.

29 The purchaser may assign its claims to third parties only with our agreement.

CONDENSING HEAT EXCHANGER CORPORATION

U.S.A.

SNC

CONDENSING HEAT EXCHANGER CORP. STANDARD CONDITIONS OF SALE

ACCEPTANCE - This is a proposal, not a firm offer, and any purchase offer issued pursuant to this proposal shall not result in a contract until it is accepted and acknowledged by CHX®. Upon such acceptance, the proposal including these Standard Conditions of Sale shall constitute the entire agreement between CHX and the purchaser and shall control over any printed terms contained in any purchase order. The sole purpose of any purchase offer submitted in response to the Proposal shall be to confirm an agreement pursuant to the terms and conditions set forth herein.

QUOTATIONS - Prices are quoted firm for a period of sixty (60) days from the date of the proposal, and are subject to change without notice after that time, provided that all quotations made by any CHX sales representative are subject to approval by Condensing Heat Exchanger Corporation, Latham, New York.

PRICES - Prices are quoted F.O.B. Warnerville, New York, and do not include any taxes or additional charges for equipment breakdown (shipping) unless otherwise stated in the quotation. Any and all applicable taxes, imposed by any federal, state, or local law, rule, or regulation shall be assumed and paid by the purchaser.

CHANGES - Either party shall have the right to propose changes in the equipment to the other party prior to delivery, but no change shall be binding on either party until incorporated into a change order to this agreement, executed by each party and specifying the effect such change will have on the price, terms and conditions of this agreement.

CANCELLATION - Any order issued by the purchaser may be cancelled only upon written notice and payment to CHX for all reasonable costs incurred (including overhead and profit) by CHX to the time that written notice is received and any costs and expenses after that time that cannot reasonably be avoided by CHX as a result of commitments made in connection with the cancelled order.

PAYMENTS - Unless specifically stated elsewhere, terms of payment are under the following schedule:

Twenty percent (20%) shall be paid upon engineering completion with approval of drawings.
Seventy percent (70%) shall be paid, net 30 days, from date of shipment.
Ten percent (10%) shall be paid, net 30 days, upon demonstration of performance or 60 days after delivery - whichever comes first.

All payments are to be in U.S. dollars. All overdue accounts will be subject to a finance charge of 1.5% per month from due date until paid.

SHIPPING - In absence of specific shipping instructions, CHX may determine the means of shipment. Shipping dates quoted are approximate and are computed from the date of receipt of customer's approval of drawings with corresponding payment. CHX will not be liable for delay in delivery due to strikes, fires, accidents, acts of God or other conditions beyond the reasonable control of CHX.

Equipment weights quoted are estimated and do not include any special packing or crating.

Maximum size of any one piece of equipment is limited by transportation regulations. CHX must be notified prior to drawing approval if equipment breakdown is required due to installation restraints.

STORAGE - The purchaser shall be responsible to protect the equipment against damage from weather or other causes, and for any cost in connection with storage or reconditioning.

TITLE - After the equipment is delivered F.O.B. Warnerville, New York, as aforesaid, title thereto shall pass to the purchaser, and purchaser shall thereafter have all risk of loss or damage due to any cause. After such delivery and until the purchase price is paid in full, CHX shall retain and the purchaser hereby grants to CHX, a security interest in the equipment as collateral security for the purchaser's obligation to pay the balance of the purchaser's price.

UNION DISPUTES - If any objection is raised by any local union at the point of installation concerning any part of the unit, the repairing and any redoing necessary to comply with the requirements of the local union will be at purchaser's cost.

PERMITS - The purchaser shall be responsible for securing any approvals or permits required by federal, state, or local laws and ordinances to operate the equipment and for paying any required fees.

FIELD SERVICE AND OPERATION - Services of factory trained and authorized field service engineers for installation supervision, equipment reassembly if breakdown was required, startup and adjustment, and subsequent technical assistance are quoted separately at standard prevailing rates. Any equipment damage resulting from improper operation or installation of the equipment by the purchaser shall be the responsibility of the purchaser. CHX will not be responsible for demonstration of equipment performance when the factory startup service is not elected; in which case the PERFORMANCE GUARANTEE shall not apply.

WARRANTY - CONDENSING HEAT EXCHANGER CORPORATION makes no express warranty of any kind except: (1) that the equipment shall conform to the material specifications and description contained in this proposal; and (2) that the equipment will be free of defects in material and workmanship. The only obligation, of CHX under this warranty shall be to repair or replace, free of charge, F.O.B. point of shipment, any parts of equipment which, by reason of defective material or workmanship, shall fail under normal use, free of abuse, negligence or accident, within 18 months from date of shipment or 12 months from date of start-up, whichever occurs first. This warranty is applicable only if written notice of any such defect is promptly given to CONDENSING HEAT EXCHANGER CORPORATION.

PERFORMANCE GUARANTEE - The performance specification set forth in this proposal is predicated on the existence of all design conditions set forth in this proposal. CHX guarantees that the equipment will recover the total amount of energy specified in the performance specification when operating at the design conditions. If the equipment fails to recover the total amount of energy specified, the sole remedy of the purchaser shall be a percentage reduction in the purchase price equal to the percentage of decrease in the amount of energy actually recovered from the amount of energy expected to be recovered in accordance with the performance specification. For this purpose, the actual amount of energy recovered shall be determined by a performance test made jointly by a factory authorized startup engineer and purchaser. Any extra tests or special testing shall be paid for by the purchaser.

LIMITATIONS - The sole liability of CHX is that which is set forth in the WARRANTY and PERFORMANCE GUARANTEE. The above warranty provisions are in lieu of all other warranties, expressed or implied, and are in lieu of all other remedies against CONDENSING HEAT EXCHANGER CORPORATION for consequential or other damages. THERE ARE NO IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE MADE IN CONNECTION WITH THE SALE.

Condensing Heat Exchanger Corp.
678 Troy-Schenectady Road • Latham, NY 12110 • (518) 785-1234

PARTIAL LISTING OF INSTALLATIONS

COMPANY NAME	
MORGAN LINEN	OCEAN STATE FINISHING
GLENS FALLS HOSPITAL	NATIVE TEXTILES
COBLESKILL HOSPITAL	FAULTLESS RUBBER
CORNELL MANUFACTURING	CIBA-GEIGY
KLEERKAST	MOBAY CHEMICAL
GENERAL MOTORS	PROCTER & GAMBLE
MANCHESTER KNITTED FASHIONS	CLEVELAND METRO GEN HOSP
NEW ENGLAND MEMORIAL HOSPITAL	CALGON CORPORATION
TIMKEN COMPANY	SCHMIDTS BREWERY
BARTON MINES	NABISCO BRANDS
AGAWAM DYE & FINISHING	NATIONAL STARCH
GOODYEAR TIRE & RUBBER	HUNT WESSON FOODS

HEATING APPLICATION	HEAT SOURCE
PROCESS WATER	BOILER FLUE GAS
LAUNDRY WATER	TEXTILE DRIER EXHAUST
DOMESTIC WATER	GAS TURBINE EXHAUST
SPACE HEATING	DIESEL GENERATOR EXHAUST
BOILER WATER & COMB. AIR	KILN EXHAUST GAS
PROCESS WATER & COMB. AIR	INCINERATOR EXHAUST
DRYER MAKEUP AIR	
BOILER MAKEUP WATER	
COMBUSTION AIR	

DIBAR INC.
C.P./P.O. BOX 65,
POINTE CLAIRE - DORVAL, QUE.
H9R 4N5

SEPTEMBER 1984

FLUE GAS RESOURCES INCORPORATED

U.S.A.

Warranty:

FLUE GAS RESOURCES, INC. ("FGR") warrants that for one (1) year from the date the glass tube heat exchanger ("GTHE") is first operated, or eighteen (18) months from the date the GTHE is delivered to the initial purchaser's jobsite, whichever occurs first, the GTHE will, under normal use and with reasonable maintenance, transfer energy as described in the plans and specifications set forth in the proposal. This warranty extends only to the original owner of the GTHE.

FGR's liability for any breach of warranty is limited to repairing or replacing at its option and without charge, any components of the GTHE which it finds defective. To obtain warranty service, all payments due under the terms of the contract must be made. Parts and service must be obtained through FGR, unless otherwise approved in writing by FGR.

This Warranty does not cover anything resulting from misuse, abuse, neglect, alteration, failure to install or operate in accordance with plans and specifications, failure to observe maintenance procedures, attempted disassembly, unauthorized repair or service, or operation of the GTHE beyond rated capacities. This Warranty does not cover costs incurred for normal repair, inspection, and preventive maintenance.

This Warranty is given expressly and in place of all other express or implied warranties or merchantability and fitness for particular purpose and this warranty is the only warranty made by FGR. This warranty does not cover and FGR shall not be liable for incidental or consequential damages.

Validity:
This proposal is valid for 90 days.

Terms of Payment for Engineering Services:
Invoiced monthly as completed; due net 30 days

Terms of Payment for Equipment:
15% invoiced upon submission of certified drawings; due net 30 days
50% invoiced upon receipt of major materials; due net 30 days and/or prior to shipping
35% invoiced upon delivery to jobsite; due net 30 days

MAINTENANCE

Routine Maintenance

General inspection and maintenance of the glass tube heat exchanger requires the following routine servicing at six month intervals (a factory serviceman is available to perform or to train your personnel in performing the following):

Inspect for broken tubes; replace tubes or plug tubesheet holes

Clear drains, remove sediment or sludge build-up from p-trap or catch basin

Check wash nozzles and clear if plugged

Inspect steel exoskeleton for corrosion

Inspect steel connecting ductwork on air side (air heater only) and hot gas side for corrosion

Inspect interior of box header for oxidation or corrosion (water heater only)

Check operation and calibration of overtemperature protection sensors and system

Important Note: Never inspect the tube bank under pressure as tubes could rupture and injure personnel!

Corrosion

Signs of any corrosion in the above areas should be brought to the immediate attention of Flue Gas Resources, Inc., recommendations will be made to repair the cause of the observed corrosion.

Emergency Maintenance

In the event of a diversion of or quenching of the hot flue gas due to an upset temperature the heat exchanger should not be returned to service until the problem causing the overtemperature situation is rectified; when the flue gas is returned to a stable condition the heat exchanger can be put back in service; the heat exchanger should be operated under observation for at least one hour when restarted after an emergency shutdown.

Cleaning

A. Gas Side:

In the event that cleaning of heat exchanger surfaces becomes necessary because of improper operation of the wash cycle the following measures should be taken.

a. Operate the wash cycle continuously for an extended period of time - up to 8 hours. This should be done with airflow across the outside of the tubes to increase scrubbing action. Washing can be affected with either hot gas or clean air (with boiler in shut down mode). Washing will not be as effective without air flow.

b. Should the above washing procedure prove ineffective, gas side cleaning can be affected with either high pressure water or steam equipment. Never attempt to free glass tubes of debris by inserting any solid object within the tube bank, as scratches to glass surfaces by metal objects can cause tube failure under pressure.

B. Water Side (Glass to be water heaters only):

In the event that internal cleaning of the glass tubes becomes necessary due to scale build-up, cleaning must be affected with commercially available detergents. Mechanical cleaning of the glass tubes is not recommended as this equipment could scratch internal surfaces, causing tubes to fail under pressure. If scale build-up is noticed during routine inspection, it is preferable to treat circulating water with commercially available chemicals to prevent build-up, as it is more difficult to clean tubes internally. If scale build-up occurs which cannot be removed with detergent washing, we recommend you contact Flue Gas Resources prior to the use of acids or solvents, as these may damage other heat exchanger components.

C. Air Side (Glass tube air heaters only):

In the event that internal tube surfaces of air heaters require cleaning, cleaning should be affected with commercially available detergents. These detergents can be applied with high pressure spraying equipment. Extreme care should be taken to insure internal tube surfaces are not scratched with metal equipment during cleaning as scratches could cause tube failure under operating conditions. If particulate build-up is noticed inside tubes during routine inspection, air filtration equipment should be installed to prevent this condition from occurring.

FLUE GAS RESOURCES OPERATING SYSTEMS LIST

CLIENT	LOCATION	BOILER FUEL	BOILER SIZE/pph steam	APPLICATION	START-UP DATE
Name Withheld	Fayetteville NC	Coal	100,000	Heating Combustion	Dec 1, 1984
Energy Advancement, Inc.	Sealy TX	Municipal Refuse	30,000	Heating Boiler makeup water	Mar 1, 1985
Kraft LTD.	Montreal QUE	Gas/Oil	70,000	Heating Process Water	Mar 1, 1985
Name Withheld	Campbellsville KY	Coal	100,000	Heating Process Water	Mar 1, 1985
Michigan South Central Power Agency	Litchfield MI	Coal	600,000	Stack Gas Cyclic Reheat System	Nov 1, 1985
Goodyear Tire & Rubber Company	Beaumont TX	Gas/Oil	200,000	Heating Boiler Makeup Water	Dec 1, 1985
Celanese Fibers Operations	Darlington SC	Gas/Oil	300,000	Heating Combustion Air	Jan 1, 1986
Procter & Gamble Company	Cincinnati OH	Gas/Oil	80,000	Heating Comb. Air & Makeup Water	Jan 1, 1986

APPENDIX H

CAPITAL COST ESTIMATE

APPENDIX H

CAPITAL COST ESTIMATE

An order of magnitude capital cost estimate was developed to compare the flue gas condensing heat exchanger designs given in Section 5.0.

The heat exchanger costs were received from vendors in foreign currencies. These costs are converted on the basis of an exchange rate effective on January 10, 1986. The U.S. Dollar was converted at Cdn$ 1.4/U.S.$ and Swiss Franc was converted at Cdn$ 0.68/SFr.

The cost of ancillaries, piping and instrumentation was based on vendor quotations and SNC's inhouse information. The cost was estimated using the general layout diagram given in Figure 5-3.

The erection and installation cost was taken to be 30% of the heat exchanger cost and 100% of the cost of ancillaries, piping, instrumentation, etc.

The contingencies were taken to be 15% for the CHX system and 25% for the glass tube (FGR) and the steel tube (AFR) heat exchanger, since Dibar Engineering and Sales, Inc. has submitted a quotation for a comprehensive packaged systems. A list of equipment supplied by various vendors is given in Appendix F.

The estimated capital costs summarized in Table H-1 have an accuracy of ± 30%.

TABLE H-1 CAPITAL COST ESTIMATE FOR INSTALLING A FLUE GAS CONDENSING HEAT RECOVERY SYSTEM ON BOILER #11

	CHX	FGR	AFR
Heat Exchanger *	826 925	484 930	230 690
Ancillaries, Piping & Instrumentation	250 000	250 000	250 000
Erection & Installation	498 078	395 479	319 207
Engineering and Services	175 268	175 268	175 268
TOTAL	1 750 321	1 305 677	975 165
Contingencies **	262 548	326 419	243 791
TOTAL CAPITAL COST	2 012 869	1 632 096	1 218 956

* All the costs are in Canadian Dollars on C.I.F. Montreal basis.

** The contingencies are 15% for CHX, and 25% for FGR and AFR.